Journal

WATER POLLUTION CONTROL FEDERATION

FORMERLY SEWAGE AND INDUSTRIAL WASTES

Special Features

Pollution Control Needs—Hollis

Radioactive Pollution—Tsivoglou et al.

Syndet Research—Weaver

Activated Sludge—Sawyer

Graphics in Reporting—Ingram and Bartsch

Operator's Corner

Gas Engines, Deeds and Data

MARCH 1960

TWO PARTS, PART 1 (*Part 2—Yearbook and Directory*)

POSITIVE CONTROL OF MATERIALS IN MOTION B-I-F METERS FEEDERS CONTROLS

NEW B-I-F MODULAR DESIGN

increases versatility, cuts maintenance in time-duration telemetering receivers

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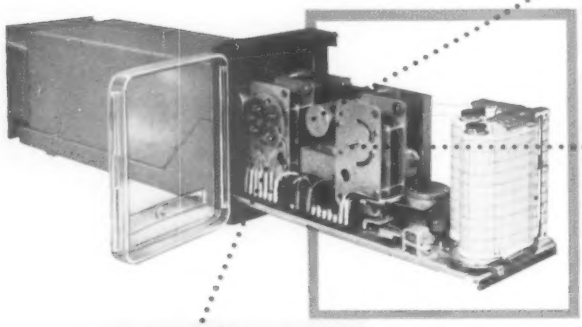
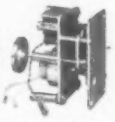
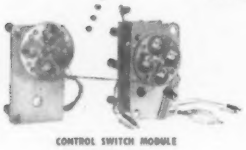


POWER SUPPLY MODULE



POWER POSITIONER MODULE



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- **High speed operation, high repeatability** . . . due to new compact, balanced-movement design of power-positioner mechanism.
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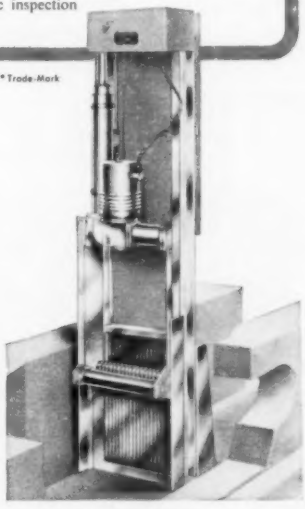

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- Ball Bearing Shoes
- Single Motor Drive . . . lower operating horsepower required
- Reversible cutting provides increased cutting capacity and extended life of cutters
- Rugged, economical design and construction

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JOURNAL of the WATER POLLUTION CONTROL FEDERATION

Volume 32 | March 1960 | Number 3

Two Parts, Part 1

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Ralph E. Fuhrman, *Editor*, 4435 Wisconsin Ave., Washington 16, D. C.

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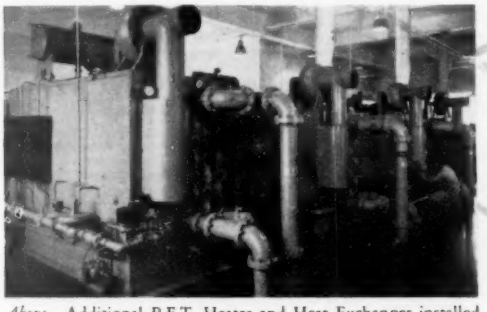
Their sewage treatment plant was completed in 1951 and included the following P.F.T. equipment: three 95′ Floating Covers, three #1500 Heaters and Heat Exchangers, three Floating Cover Position Indicators, Gas Safety Equipment.

Continuing their program, in 1958 P.F.T. equipment was *again* selected which included: one 95′ Floating Cover, another #1500 Heater and Heat Exchanger and a Floating Cover Position Indicator.

1958's additions embodied all the latest digestion controls including P.F.T. Pearth Gas Recirculation for increased effectiveness of the new unit.

Plant designed by—Engineering Department—East Bay Municipal Utility District.

Above—P.F.T.'s Pearth Gas Recirculation equipment on newly added 95′ P.F.T. Floating Cover Digester.



Above—Additional P.F.T. Heater and Heat Exchanger installed in 1958. Notice the perfect blending with those installed in 1951.

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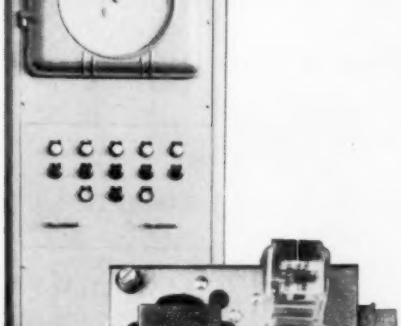
In the basic system the generator produces both a dc and a 60-cycle ac signal which is unscrambled at the receiving end by the selector. These 2 signals are fed into a multiplexing unit which provides the extra channels.

Uses ac and dc signals—Combining ac and dc currents produces a circuit less affected by line capacitance and able to give a longer distance transmission with available capacitance.

The new system requires much less maintenance than previous designs. It uses no vacuum tubes, eliminates all motorized timers and motorized sequence switches; and the modular units are equipped with "quick-disconnect" connectors, plug-in relays, and rectifiers of advanced design.

Modular design—The modular design allows building up as many as 29 separate channels for supervisory indicators, alarms, telemeter receivers, pump controls, valve positioners, etc.

For complete specifications and design theory, write for bulletin to our Simplex Division, Dept. SI-10, Lancaster, Pa.



BIPLEX Selector separates signals so they operate relays sensitive only to their assigned signal.

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Association	*Place*	*Time*
Arkansas Water and Sewage Conf.	Marion Hotel Little Rock, Ark.	Mar. 13–16
Louisiana Conference on Water Supply and Sewerage	La. State Univ. Baton Rouge, La.	Mar. 16–18
West Virginia Water Pollution Control Assn.	Hotel Pritchard Huntington, W. Va.	Mar. 23–24
New Jersey Sewage and Industrial Wastes Assn.	Traymore Hotel Atlantic City, N. J.	Mar. 30–Apr. 1
Kansas Sewage and Industrial Wastes Assn.	Broadview Hotel Emporia, Kans.	Apr. 22–24
California Sewage and Industrial Wastes Assn.	Hotel Claremont Berkeley, Calif.	Apr. 27–30
Arizona Sewage and Water Works Assn.	Pioneer Hotel Tucson, Ariz.	Apr. 28–30
Montana Sewage and Industrial Wastes Assn.	Northern Hotel Billings, Mont.	Apr. 28–30
Michigan Sewage and Industrial Wastes Assn.	Park Place Hotel Traverse City, Mich.	May 23–25
Föreningen för Vattenhygien (Sweden)	Institutet för Arbetshygien Helsinki, Finland	May 27–29
Alabama Water and Sewage Assn.	60 Auburn University Auburn, Alabama	June 6–8
Maryland-Delaware Water and Sewage Assn.	Alexander Hotel Hagerstown, Md.	June 8–10

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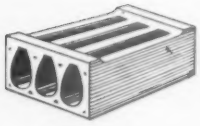

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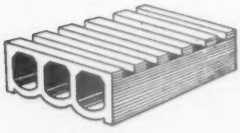

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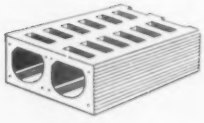

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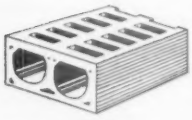


BOSCO

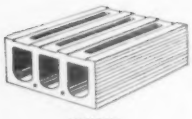
Bowerston Shale Co.
Bowerston, Ohio

Dumping raw and inadequately treated sewage into streams which are downstream communities' source of water supply is of necessity nearing an end. Anticipate now their demands for protection from your sewage and industrial wastes by building trickling filters. The number of them built since 1945 is overwhelming evidence that these filters are the average city or industry's best answer to wastes treatment needs.

The most vital part of these trickling filters is the underdrain system. Failures here spell real trouble later. But when the floor is of TFFI Specification vitrified clay blocks this is guarded against. For it is inherent in clay to resist successfully the ravages of acids, alkalis and bacteriological action. TFFI clay underdrain blocks are made in modern plants under rigid controls of quality that no substitute material can even approach. (Only with them can you get a 50-Year Guarantee.)

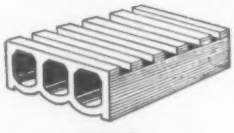
Any member of the Institute listed on this page will be glad to send you a copy of the new approved specifications A.S.T.M. C 159–59T for use in designing trickling filters.

TRICKLING FILTER FLOOR INSTITUTE



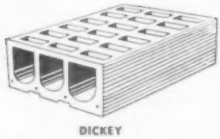
POMONA

Pomona Terra-Cotta Co.
Pomona, No. Car.



TRANSLOT

Texas Vitrified Pipe Co.
Mineral Wells, Texas



DICKEY

W. S. Dickey Clay Mfg. Co.
Kansas City 6, Mo.

IF YOU DON'T HAVE A TRUCK-LODER *Your Sewer Crew is WORKING TOO HARD!*

PATENT 2,892,557

LOADS DIRECT INTO TRUCK

ENDS DUMPING SEWERAGE ON STREETS!

RELIEVES WORKERS OF 3 HARD JOBS!

The **TRUCK-LODER** frees your workers from the hard jobs of manually dumping the bucket on the street — shoveling deposits into the truck, and cleaning up the street.

With the **TRUCK-LODER** two men can accomplish far more than four with conventional bucket machines, thereby freeing the extra men for other important sewer maintenance work.

Users report the elimination of time-consuming operations has increased sewer-cleaning capacity by 40%. They agree that **TRUCK-LODER Bucket Machines exceed all performance estimates.**

Your Flexible representative will be glad to give you facts and figures at your convenience.

Use With Your Present Machines

Use Truck-Loders on the dumping end and your regular machines on the Pull-In end. Net result—two complete, modern Truck-Loder units.

★★★

FLEXIBLE INC.

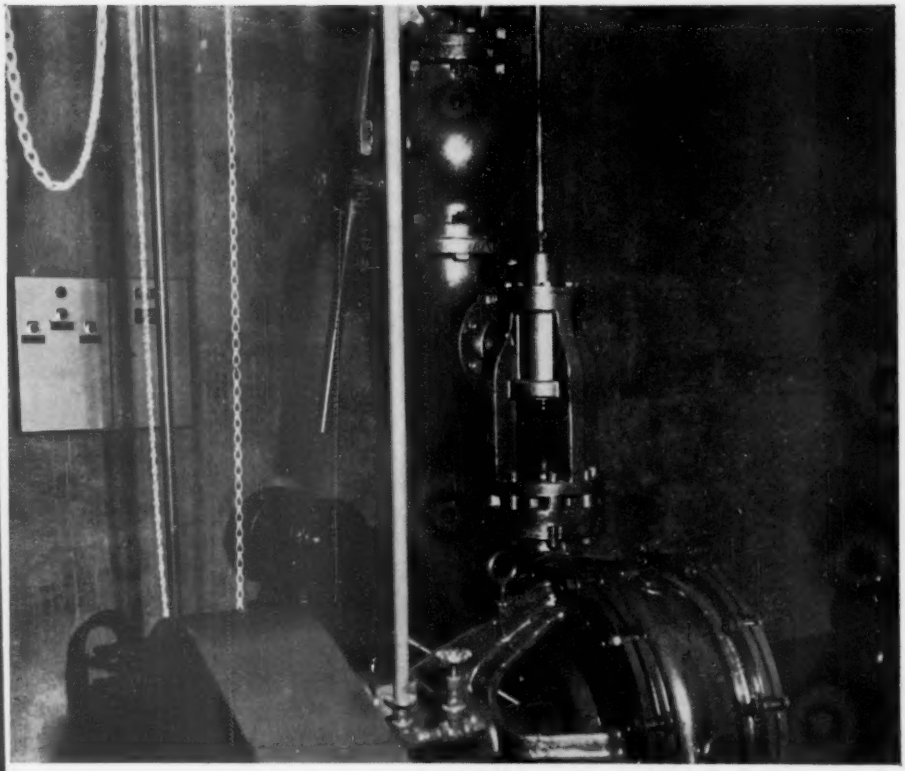
3786 DURANGO AVE., LOS ANGELES 34, CALIF.
1005 SPENCERVILLE ROAD, LIMA, OHIO
415 SOUTH ZANGS BLVD., DALLAS, TEXAS

★★★

No dog, this seeing eye!

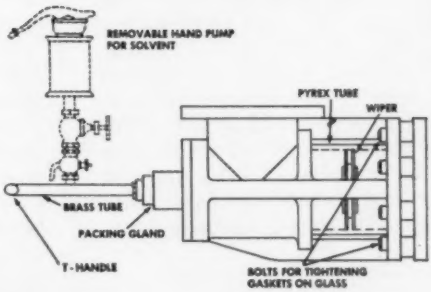
What started out as a favor to a friend (development of a Cleanable Sight Glass) has turned into one of our most gratifying enterprises. While not unusually profitable as a commercial venture, the good will implications are immense: over 500 sewage, water and industrial waste treatment plant operators throughout the world feel kindly toward Eimco-Process equipment because they can now *visually* control sludge withdrawal.

Think of it. Instead of guessing at that critical point where the heavy layer ends, they can see it. Instead of flying blind, they can witness the phenomenon of thin sludge being pulled through the heavy layer and, of course, take prompt remedial action (like shutting off the pump). And if grease in the sludge clouds the inside of the Pyrex, a little solvent injected through the hollow wiper rod and a few deft swipes of the wiper clear matters instantly.



Our obligation is clear: to make this inexpensive adjunct to efficient plant operation available to all operators as quickly as Eimco production schedules permit.

Your part is simple: if you have a 4" or 6" standard elbow in your sludge line, wire your Cleanable Sight Glass order and stand by with wrenches. Or, if you want to contemplate more facts and figures, send for Bulletin SM-1002. Either way, may we hear from you?



THE EIMCO CORPORATION

Process Engineers Division
420 Peninsular Avenue
San Mateo, California

B - 582

Armco Sluice Gates Help Boost Treatment Plant Capacity

The gate being lowered into position above is one of three 72-inch by 96-inch Armco Sluice Gates installed at the Hyperion Sewage Treatment Plant near El Segundo, California. These gates, located in the headworks building and equipped with electrically operated lifts, are one phase of a plan to increase plant capacity. The gates, normally open, are closed only for maintenance work.

Two smaller Armco Sluice Gates and two stainless steel flap gates were used in other parts of the plant.

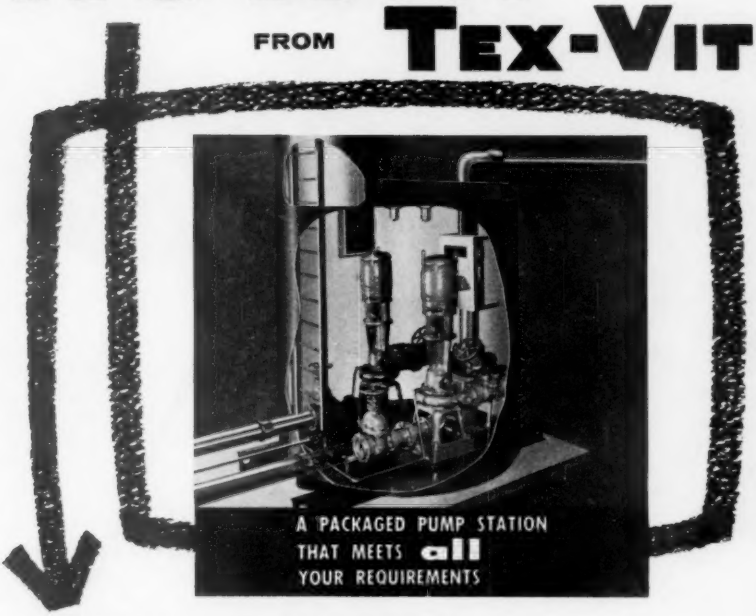
Armco can help solve *your* gate problems, too. For complete data, write: Armco Drainage & Metal Products, Inc., 4950 Curtis Street, Middletown, Ohio.

ARMCO DRAINAGE & METAL PRODUCTS

Subsidiary of ARMCO STEEL CORPORATION

OTHER SUBSIDIARIES AND DIVISIONS: Armco Division • Sheffield Division
The National Supply Company • The Armco International Corporation
Union Wire Rope Corporation

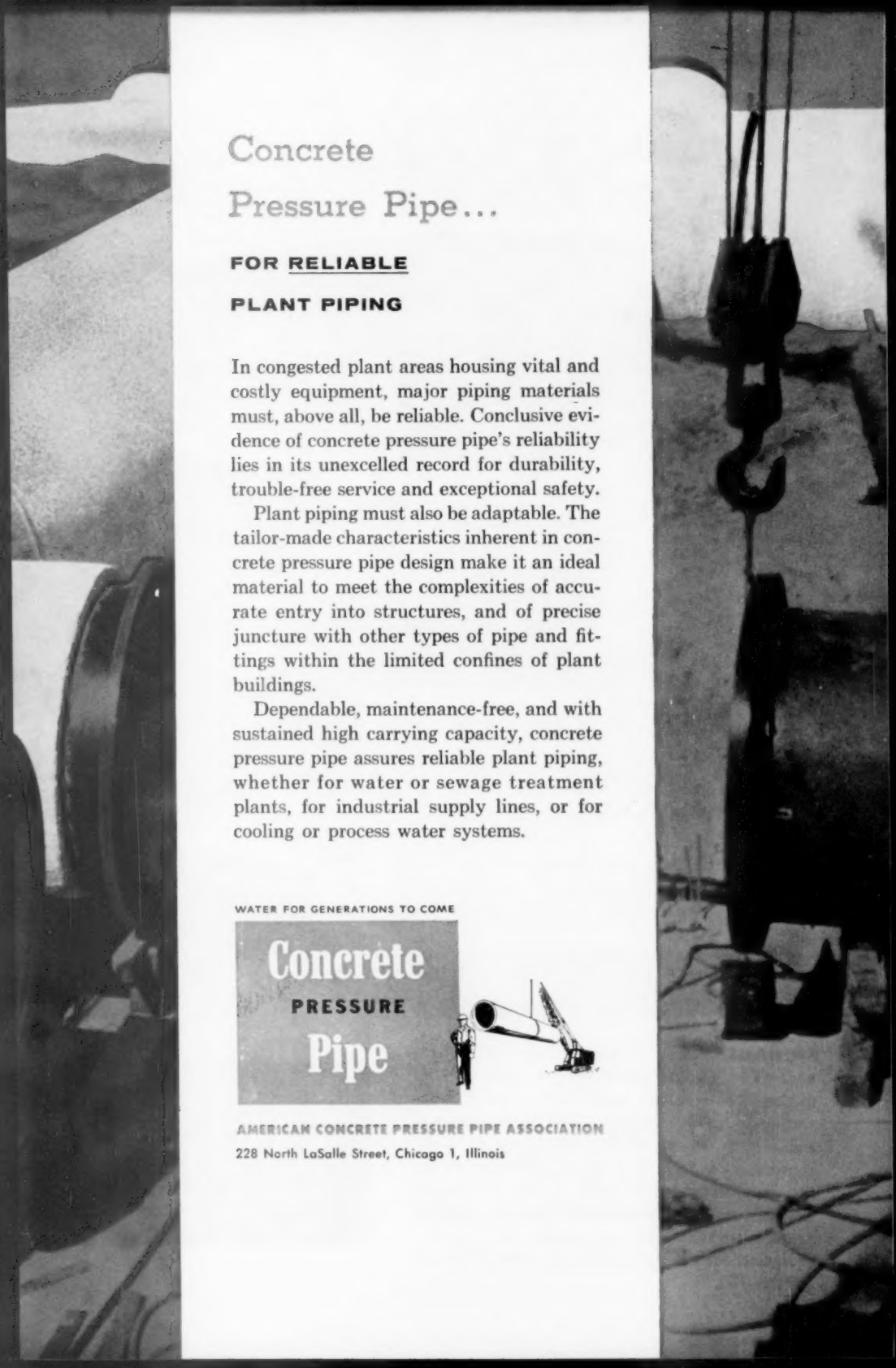
NOW... FROM TEX-VIT



- **ADVANCED DESIGN FOR GREATER EFFICIENCY**
  Compare motor and pump assembly of this duplex sewage pump station with any other and see the TEX-VIT superiority. Individual shaft for each pump and each motor. Four bearings per assembly instead of the customary two. Heavy steel shell, completely protected from corrosion.
- **DIRECT PRESSURE CONTROLS FOR EXTRA RELIABILITY**
  Exclusive TEX-VIT controls are actuated by pressure variations within the wet well. No compressor to maintain; no floats or other moving parts in the wet well.
- **IMPROVED AIR CIRCULATION AND CONDITIONING**
  Extra large blower provides complete change of air every 60 seconds. Air inlet and outlet are at opposite sides of station to prevent short circuiting of air. Refrigeration-type dehumidifier.
- **SUPERIOR COMPONENTS FOR EXTRA DEPENDABILITY**
  Pumps, motors, controls, and other components bear the brand names you would expect to find in a *Who's Who of American Industry*. You know you are getting the best when you specify TEX-VIT.
- **INSTALLATION TESTED AND PROVED**
  TEX-VIT packaged pump stations are setting new standards. Names of muncipal and industrial users furnished on request.
  Let TEX-VIT help you with your sewage lift problems. TEX-VIT also makes pneumatic ejectors and packaged ejector stations.

Write for bulletin No. PS-60

TEX-VIT
SUPPLY COMPANY
MANUFACTURING DIVISION
Dept. S-3, Box 117, Mineral Wells, Texas



Concrete Pressure Pipe...

FOR RELIABLE PLANT PIPING

In congested plant areas housing vital and costly equipment, major piping materials must, above all, be reliable. Conclusive evidence of concrete pressure pipe's reliability lies in its unexcelled record for durability, trouble-free service and exceptional safety.

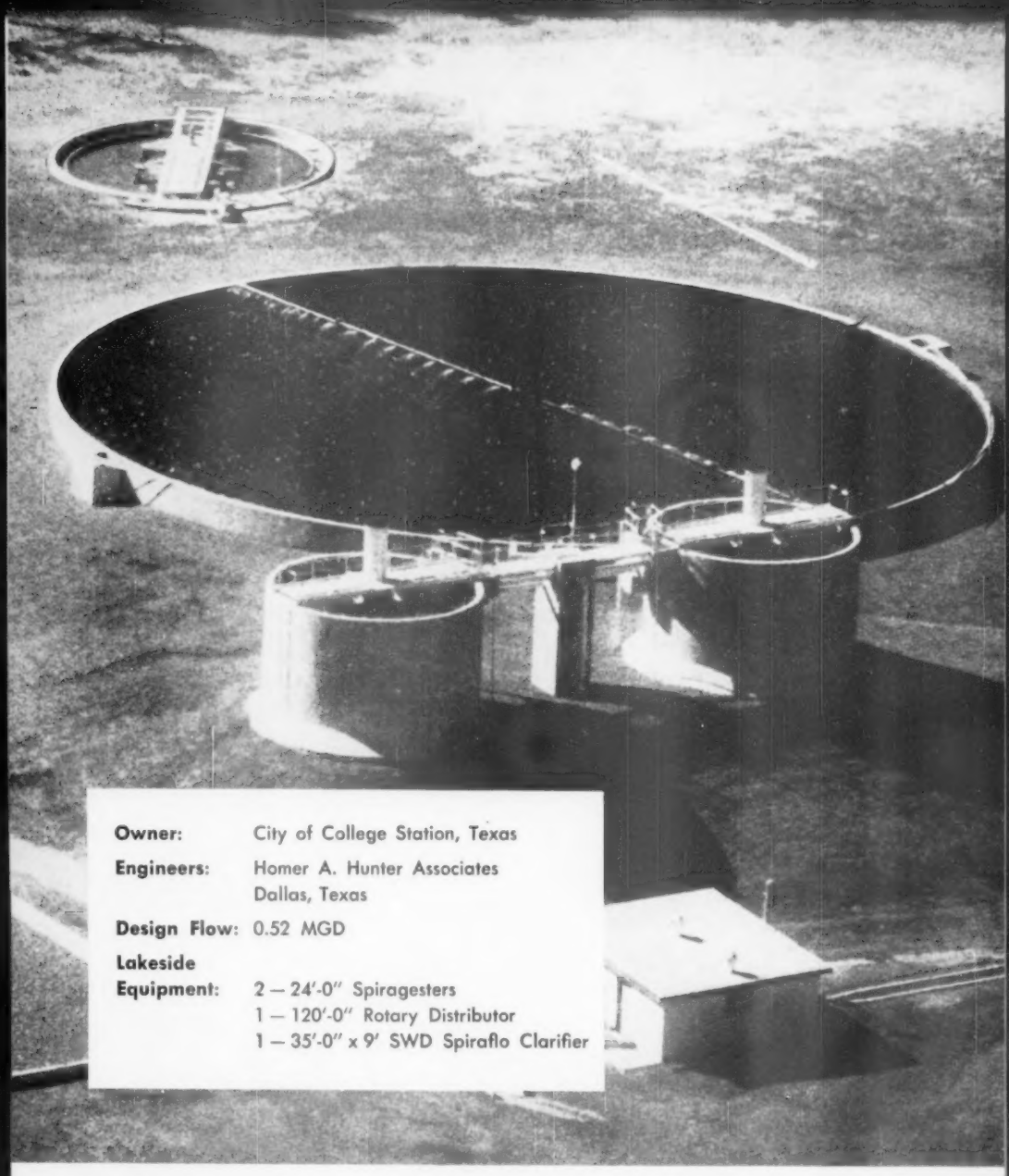
Plant piping must also be adaptable. The tailor-made characteristics inherent in concrete pressure pipe design make it an ideal material to meet the complexities of accurate entry into structures, and of precise juncture with other types of pipe and fittings within the limited confines of plant buildings.

Dependable, maintenance-free, and with sustained high carrying capacity, concrete pressure pipe assures reliable plant piping, whether for water or sewage treatment plants, for industrial supply lines, or for cooling or process water systems.

WATER FOR GENERATIONS TO COME

Concrete PRESSURE Pipe

AMERICAN CONCRETE PRESSURE PIPE ASSOCIATION
228 North LaSalle Street, Chicago 1, Illinois



Owner:	City of College Station, Texas
Engineers:	Homer A. Hunter Associates Dallas, Texas
Design Flow:	0.52 MGD
Lakeside Equipment:	2 — 24'-0" Spiragesters 1 — 120'-0" Rotary Distributor 1 — 35'-0" x 9' SWD Spiraflo Clarifier

SPIRAGESTERS® are used singly for projects under 6000 P.E. They give superior results with the minimum of operating skill. Construction and operating costs are among the lowest. Plant expansion available by adding another Spiragester or easily converting the tank to a digester. Spiragesters are now installed throughout the U. S. Also Canada and foreign countries. As at College Station, Lakeside provides trickling filter and Spiraflo final clarifier equipment for a complete treatment plant. *Write for Bulletin 100.*

LAKESIDE

ENGINEERING CORPORATION

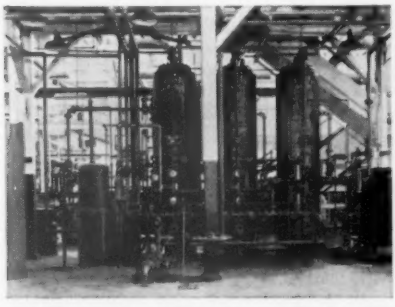
222 West Adams St., Chicago 6, Illinois

FLUIDICS

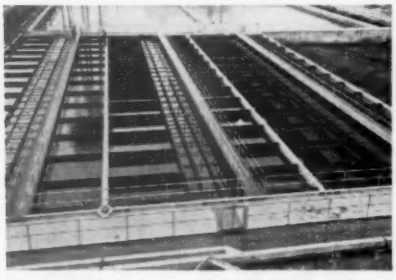
is a Pfaudler Permutit program providing

the know-how
the equipment
and the experience
for solving problems
involving fluids

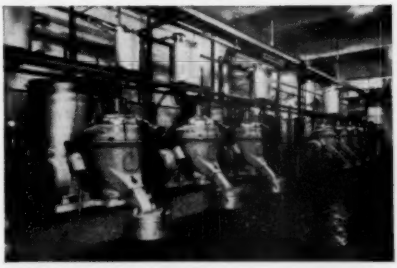
FOR WASTE TREATMENT, the Fluidics program provides a wide range of specialized equipment and technical service to help you efficiently recover valuable materials and easily dispose of unwanted wastes.



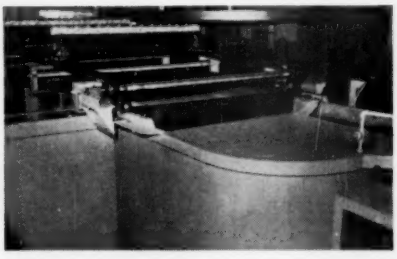
Purification of liquids and recovery of dissolved minerals from plating solutions, pickling baths, textile wastes, process solutions and similar fluids are assured with unique effectiveness by Permutit Ion Exchangers. Recovery of valuable materials often pays for equipment within a short time.



Sludge blanket clarification of fluids requiring removal of suspended solids such as fly ash, precipitates, turbidity, etc. is accomplished with high efficiency by the Permutit Precipitator.



Dewatering Sludges. Titan Centr fuge exerts settling power up to 7800 times gravity. Concentrates slimes and clarifies liquids. Precisely separates two liquids and a solid in a single pass. Dewaters plating wastes, protein fines and flocculent precipitates. Recovers oil from tank bottoms, fat from waste, and pulp from white water. Saves product, filter aid, power and maintenance.



Flotation clarification of fluids containing fats, oils, greases, organics and colloidal suspensions is done quickly, effectively and economically with the Permutit Colloidair Separator.

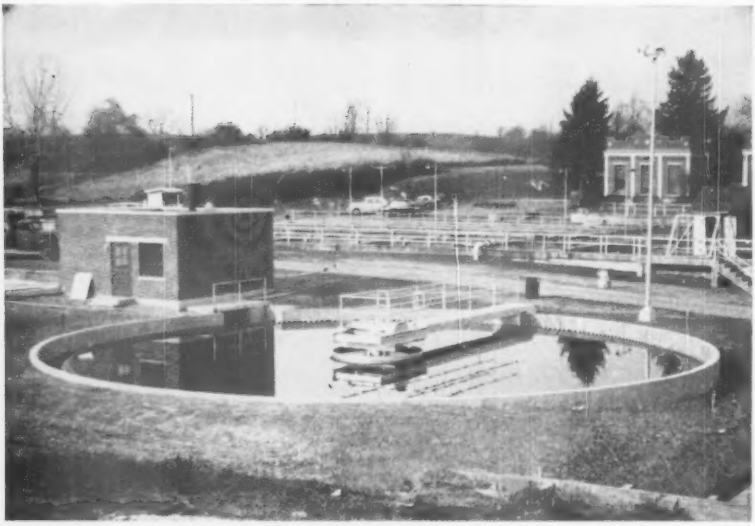
Add to this equipment our Simplex meters and flow controllers, Permutit chemical feeders, filters and vacuum degasifiers, Ranarex CO_2 indicators and recorders, and Pfaudler evaporator systems, and you get an idea of the scope of this program in just the waste treatment area of fluid processing. Yet Fluidics is a program that provides more than just equipment. You can get complete engineering assistance as well as expert advice based upon more than 50 years' experience in fluid waste control.

For more information on how Fluidics can help in your waste treatment program, contact our Permutit Division, 50 West 44th Street, New York 36, N. Y.

In Canada: 207 Queen's Quay W., Toronto 1, Ontario.

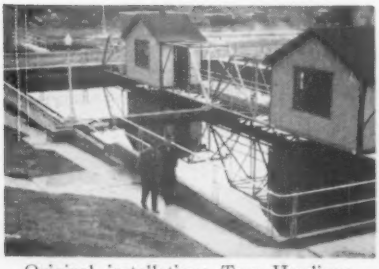
PFAUDLER PERMUTIT INC.

Specialists in FLUIDICS . . . the science of fluid processes



Hardinge Center-Column Clarifier recently installed at the Hagerstown Sewage Plant

another HARDINGE Clarifier for HAGERSTOWN



Original installation: Two Hardinge Rotary Clarifier Mechanisms in rectangular tanks (1932).

Second installation: A Hardinge Beam-Supported Primary Clarifier doing heavy duty (1949).

HARDINGE
COMPANY, INCORPORATED

YORK, PENNSYLVANIA • 240 Arch St. • Main Office and Works

New York • Toronto • Chicago • Nibbing • Houston • Salt Lake City • San Francisco • Birmingham • Jacksonville Beach

MADISONVILLE, KY., has had no property taxes for three successive years. With this record of efficient management, it is only natural that Clay Pipe should be chosen for the city's new sewerage expansion system. More than twenty-two miles of Vitrified Clay Pipe are going into the project.

Clay Pipe was the natural choice because it does not rust, rot, corrode, or disintegrate . . . never wears out. And new, longer, stronger lengths speed installation . . . cut labor costs.

Only Clay Pipe has *all* the features you can trust.

Public Officials: David Parish, Mayor; A. O. Johnston, Councilman, Chairman of Water and Sewers.

Consulting Engineers: J. Sanders Parker; F. E. Stepp, Resident Engineer.

Contractors: C.F.W. Construction Co., Inc.; Sterrett Construction Co.

C-455-1A

Vitrified **CLAY PIPE** *Never Wears Out*

NATIONAL CLAY PIPE MANUFACTURERS, INC.

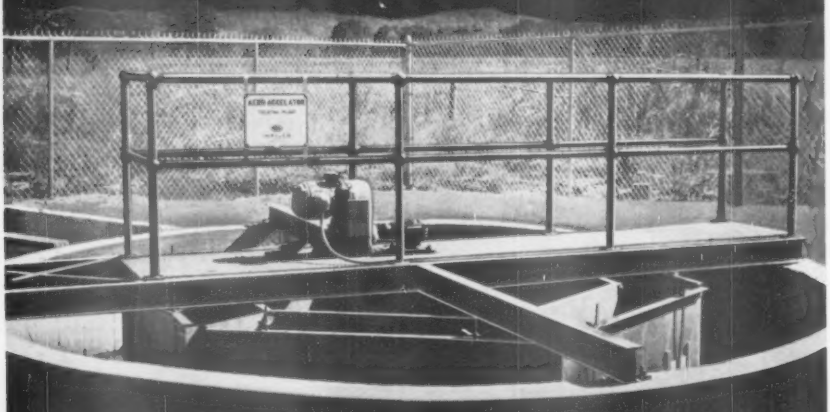
1820 N St. N. W., Washington 6, D. C.

311 High Long Bldg., 5 E. Long St., Columbus 15, Ohio • 445 Ninth St., San Francisco 3, Calif.
Box 172, Barrington, Illinois • 1401 Peachtree St., N. E., Atlanta 9, Georgia

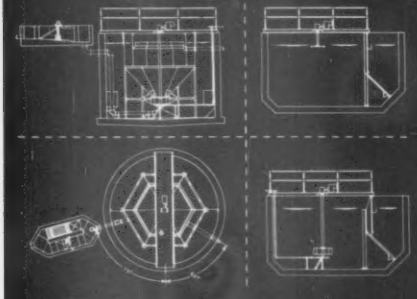
ECONOMICAL B.O.D. REMOVAL BY "TOTAL OXIDATION" SEWAGE PLANTS

for subdivisions, shopping centers, small municipalities, hotels, institutions, camps, resorts and similar projects

See your Consulting Engineer



Typical ACCELO-BIOX® plants



Whatever your need may be for small sewage treatment, INFILCO offers you standardized equipment applications that are economical, efficient and compact.

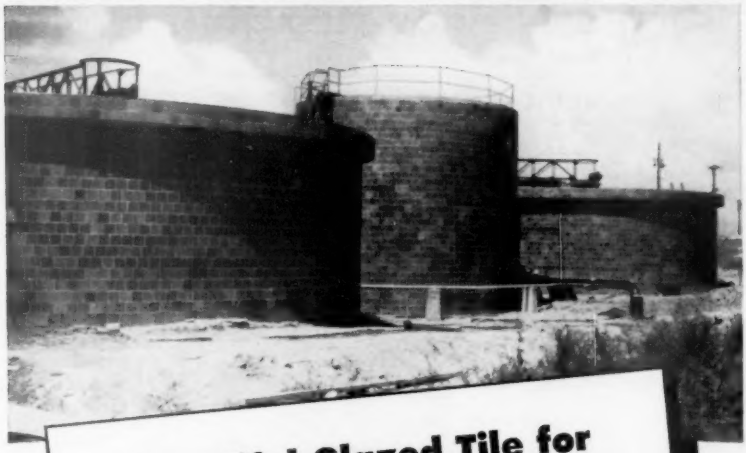
It will pay you to investigate. Write today for complete information.

INFILCO

INFILCO INC.
General offices
TUCSON, ARIZONA

FIELD OFFICES THROUGHOUT THE UNITED STATES AND IN OTHER COUNTRIES 6021

Effluent and Water Treatment Tanks



Beautiful Glazed Tile for Complete Corrosion Resistance

•

Comparable in Cost to Concrete or Steel... No Continuing Maintenance

Stebbins SEMTILE® and SEMBLOK® tanks are, in effect, reinforced concrete structures faced on both sides with vitrified tile. No form work is required. Contours and dimensions can be varied to fit all types of specialized equipment.

Installations can be made under a contract which covers everything from the original design, based on full knowledge of the chemical, physical and mechanical requirements, to the finished job ready for use.

Write for complete information

SEMCO

STEBBINS Engineering and Manufacturing Company

WATERTOWN, N. Y. • PENSACOLA, FLORIDA

STEBBINS ENGINEERING CORP — TOWER BLDG., SEATTLE, WASH.

CANADIAN STEBBINS ENGR. & MFG. CO., LTD — TOWN OF MOUNT ROYAL, MONTREAL 9, CANADA

SINCE 1884

Specialists in Design, Installation and Servicing of Linings and Tile Tanks

SYMBOLIC LOGIC

AEIOU ≠ (AWW = Z)

Take the phrase

"AMERICAN WELL WORKS OR EQUAL—"

Let AWW *stand for American Well Works*

Let Z *stand for all things equal to* AWW

Let the entire set of "vocal vowels" stand for what's not equal to AWW

Now, AWW *has the following attributes:*

- Experience rating of 92 years.
- Its sole business is engineering, design and manufacturing of equipment for sewage treatment, water purification, mixing and pumping. It has no outside activities.
- It owns extensive plant, equipment and manufacturing facilities all on one site to assure complete quality control.
- All of its products are unconditionally guaranteed as to function and performance.
- Its products are reasonably priced to enable owners and engineers to stay within estimates.
- It offers latest proved methods and designs.
- It has the highest available mercantile credit rating.
- It has the largest list of satisfied users in the United States.

THE PROBLEM:

Ignoring the entire set of "vocal vowels" (which are admittedly not equal to AWW*) solve for* Z *(what's equal to* AWW*)*

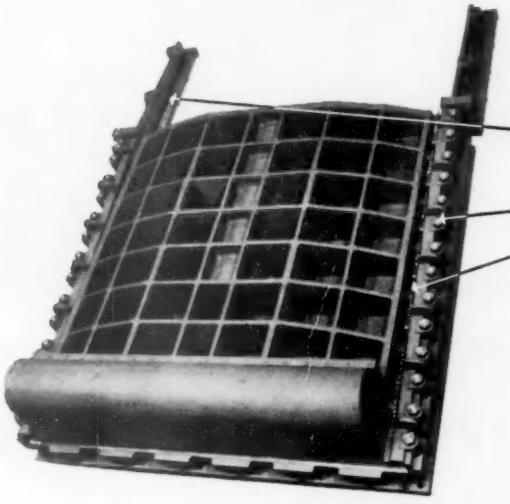
HINT FROM AWW *ENGINEERING DEPARTMENT:*

Even if Z *could easily be determined,*

Take AWW *for assured advantages*

AMERICAN WELL WORKS AURORA, ILLINOIS

2,300 pounds of Everdur used in new 8-ton cast-iron sluice gate



1 ¾" x 3" Everdur facing strips for gate leaf and frame.

2 1½" Everdur bolts and nuts.

3 Everdur adjusting bolts for cast-bronze wedges.

More than a ton of Everdur was used for facing strips and fastenings in this 8' x 8' sluice gate leaf and frame assembly designed and furnished by the Coldwell-Wilcox Division of Krajewski-Pesant Mfg. Corp., New York City. Consulting engineers, Gannett Fleming Corddry & Carpenter, Inc., Harrisburg, Pa.

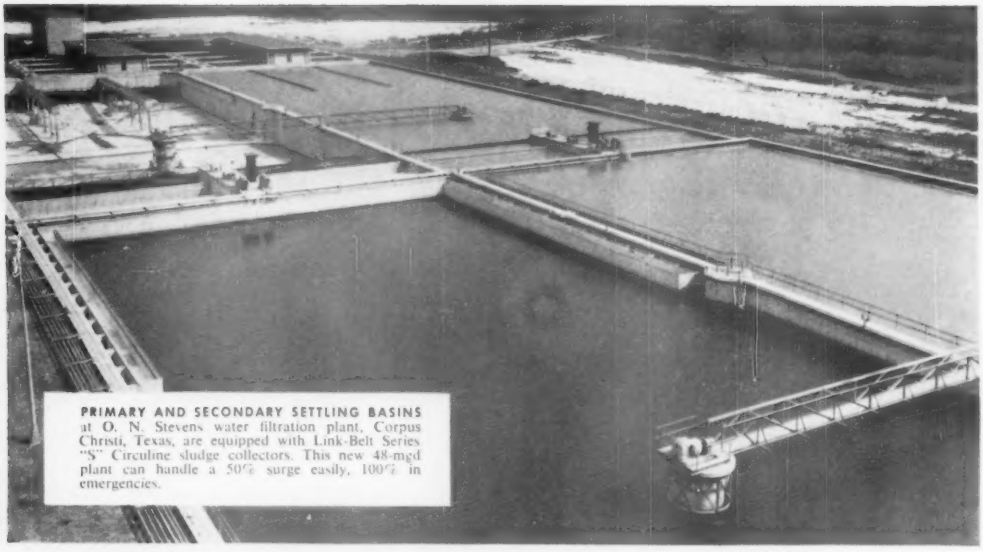
This direct-pressure type sluice gate is one of two recently installed by Empresa de Energia Electrica at the Quebradona Dam in Columbia, South America, to regulate the flow of potable water to the city of Medellin.

The 100-foot head of water behind the dam exerts 450,000 pounds pressure on each 8 x 8-foot gate. Everdur* (copper-silicon alloy) was selected to seal against this load because of its high strength and corrosion resistance—plus ready workability and weldability. Sewage treatment and water works equipment of Everdur has been in service without replacement for a quarter century and longer.

Write for Publication E-11, "Everdur Copper-Silicon Alloys for Sewage Treatment and Waterworks Equipment"—or for technical help in selecting the correct material for your job. Address: The American Brass Company, Waterbury 20, Conn. In Canada: Anaconda American Brass Limited, New Toronto, Ont.

*Reg. U.S. Pat. Off. 57133

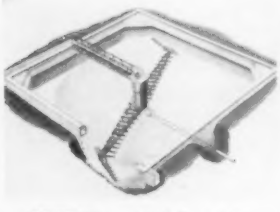
EVERDUR Anaconda's Family of Copper-Silicon Alloys
MADE BY THE AMERICAN BRASS COMPANY
STRONG · WORKABLE · WELDABLE · CORROSION-RESISTANT



PRIMARY AND SECONDARY SETTLING BASINS at O. N. Stevens water filtration plant, Corpus Christi, Texas, are equipped with Link-Belt Series "S" Circuline sludge collectors. This new 48-mgd plant can handle a 50% surge easily, 100% in emergencies.

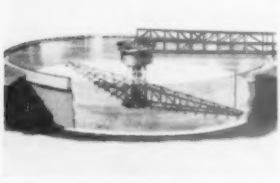
Four series of LINK-BELT Circuline collectors

offer positive sludge removal

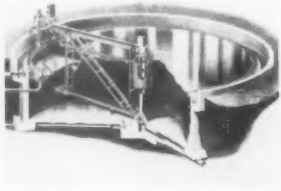


SERIES "S" — specially designed for square and rectangular tanks. As collector revolves, pivoted arms on ends of rakes adjust to thoroughly remove sludge from basin corners.

SERIES "R" — available in models for bottom feed, side feed or cross flow applications . . . in a wide range of sizes. Pitched blades gently convey sludge to center of tank.



SERIES "T" THICKENER — for rugged duty. Similar to "R" collectors except for heavier design. Furnished with fixed rake and automatic or manual lift types.



SERIES "C" — uses simple, positive traction drive to rotate bridge. Slow-speed straightline collector, with long-wearing, corrosion-resistant chains, removes sludge.

There's a design to fit any requirement of tank capacity or construction

THERE's no problem of septicity in settling tanks where Link-Belt Circuline collectors are used. Traveling smoothly and gently, they assure minimum disturbance of flow and the greatest possible concentration and removal of solids in least time.

This efficiency is typical of all the equipment in the complete Link-Belt line for water, sewage and industrial liquids treatment. And it testifies to the value of Link-Belt's more than 35 years' experience in sanitary engineering.

Link-Belt will gladly work with your consultants and chemists on *any* treatment problem. Call your nearby Link-Belt office. Send for Book No. 2546. 15.230

LINK-BELT

SANITARY ENGINEERING EQUIPMENT

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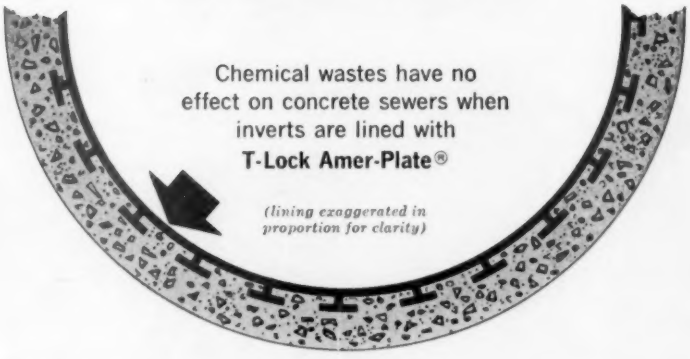
How to Protect Concrete Sewers from Chemical Wastes



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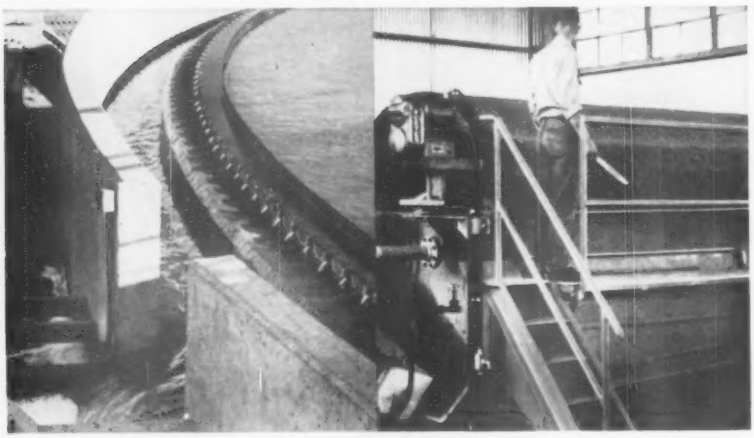

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WATER RESOURCES AND NEEDS FOR POLLUTION CONTROL *

By Mark D. Hollis

Assistant Surgeon General and Chief Engineer, Public Health Service, Department of Health, Education, and Welfare, Washington 25, D. C.

It is an interesting commentary, in this advanced age of science and technology, that water—one of the most plentiful substances—remains an essential key to man's progress. Water—its use and misuse—is a number one national issue.

The explosive population growth in a technologically superb economy—with growing needs, and with higher standards of national demand—now taxes to the hilt the essentially fixed water resources. In a situation that calls for calm, rational apportionment in the spirit of allied interests, there are instead tense, highly competitive pressures to commit ever more water to various competing uses—domestic, industry, power, agriculture, navigation, wildlife, and recreation. The needs for water climb to astronomical figures. When summing domestic requirements for water and those that go into production of the things to eat and wear and use, the per capita need exceeds 1,200 gallons per day. At the same time in many shortage areas, far too much water is made literally useless by uncontrolled pollution. Today, water pollution control very definitely is a major instrument in water resource conservation.

Also, there is the need to recognize that the concept of the values of water must be continually adjusted to suit the changing public demands. For example, recreational, fishing, and wildlife interests are literally forcing their way into watershed management without regard for existing likes or dislikes.

The direct linkage between demands on water resources on the one hand and population growth and technological advancement on the other, certainly indicates no letup in the order of things.

The U. S. population is now past 178 million—up 40 per cent in the past 25 years. By 1980, predictions are for the 260 million range—up 50 per cent in just two decades. The present increase is at the rate of 1 each 12 seconds, or 2,628,000 per year. Metropolitan growth trends continue. Within two decades, three-fourths of the population will live in metropolitan centers. There will be a development of continuous metropolitan-industrial complexes extending hundreds of miles along super highways and major waterways.

The technological pattern is even more fantastic. This holds when viewed by almost any yardstick—gross national product, new materials, energy requirements, transportation, or communication.

To illustrate the fantastic doctrine of change: in the few postwar years man has learned to propel himself at

* Presented at the 32nd Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Dallas, Tex.; Oct. 12–15, 1959.

twice the speed of sound; has pierced the depths of the atom; has placed in orbit new moons to probe outer space; has established "breeder" techniques for the continuous flow of new products from the marvels of modern chemistry; has taken great strides in the field of automation; and has tapped energy sources of unprecedented potential.

To take yardsticks more directly related to water pollution: hundreds of new synthetics are in commercial production and use to produce new construction materials, wearing apparel, pharmaceuticals, and even foods. Last year some 500 million pounds of economic poisons were produced for use as insecticides, fungicides, weedicides, and chemical fertilizers.

In this tidal wave toward the technological utopia of push-button living, it becomes more and more difficult to maintain some order of balance in the physical environment. This certainly will not be easy. Water resources is a prime example.

This is the setting at this time—replete with contradictions, frustrations, conflicts, and competitions. As one reflects upon the next few decades, with water resources in mind, agreement would be expected on at least four predictions.

1. That explosive population growth in the economic pattern is resulting in closely knit, gigantic metropolitan-industrial complexes—which situation will increase at fantastic rates.

2. That there will be a continuing avalanche of technological change at an ever-increasing tempo, at rates so rapid as largely to outmode traditional methods of measuring and equating impacts on water resources, both quantitatively and qualitatively.

3. That at some point on this growth curve, the predictable microbiological pollution, together with the less predictable contaminants from exotic chemical substances, will produce composite effects with sobering potentials.

4. That conventional waste treatment technology simply is not abreast of the trends of the times; that at best it can, at a price, moderate traditional organic pollution, but certainly is not geared to the expected buildup in wastes from new substances.

Lest this last point be viewed as too harsh an indictment, a more specific example is offered:

At present, 100 million people depend on surface streams for drinking water. Table I reflects the current and projected situation in terms of population served by various classes of surface raw water supplies, which classes, for purposes of this paper, are defined:

1. Class A—Water sources plentiful in supply for the anticipated population and of relatively high quality (such that no unusually difficult problems of treatment exist). Examples would be the Great Lakes Area and the generally excellent upland raw waters now used in New England.

TABLE I.—Population Served by Various Classes of Surface Raw Water Supplies

Class	Water Source Classification	1960		1980		2000	
		Population (million)	Per Cent	Population (million)	Per Cent	Population (million)	Per Cent
A	Adequate in quantity and quality	53	53	82	50	121	47
B	Adequate in quantity but low in quality	42	42	71	43	113	44
C	Inadequate in quantity and quality	5	5	12	7	25	9
Total		100	100	165	100	259	100

2. Class B—Water sources generally plentiful in supply but of poor to very poor quality, necessitating expensive, frustrating, and troublesome treatment. Examples would be the Ohio and Missouri Rivers, and other streams subject to extensive growing and changing pollution.

3. Class C—Water sources subject not only to serious shortages with respect to demands, but also subject to very serious quality problems. Examples would be certain water sources in the Arkansas and Red River Basins.

In developing these data, certain assumptions were made: (*a*) that essentially all major metropolitan waste by 1980 will be receiving so-called "complete" treatment; (*b*) that industrial waste per se will be under reasonable control; (*c*) no allowance for possible major breakthroughs in reclaiming waters of extremely poor quality; and (*d*) no significant diversion of water over long distances between major basins.

Analysis of Data

Considering the years 1960, 1980, and 2000, as shown in Table I, while the municipal population blessed with Class A water sources will increase from 53 to 121 million, the percentage of total served will decrease from 53 to 47 per cent. This is to be expected, and the decrease would be much more apparent except for the influence of the Great Lakes Area. (The Class A group includes metropolitan New York, Chicago, Los Angeles, and San Francisco, representing almost 40 per cent of the total).

With respect to Class C waters, the figures are relatively low, but obviously highly significant to those millions of Americans affected. Improvements in this class will depend on major breakthroughs in our water or waste treatment technology or major interbasin distribution of water supplies.

The data with respect to Class B water are of more direct and immediate concern to the day-to-day interest of the Federation. These source supplies now serve 42 million people or 42 per cent of the total population currently using surface supplies. It is of interest that the percentage factor will hold about constant for this class as the population dependence moves upward to 71 million in 1980 and to 113 million in the year 2000.

Keep in mind that the quality factor in the breakdown definition for Class B is from "poor" to "very poor." There is no question but that the quality of these waters will shade toward the "very poor" in the years ahead, especially in terms of the new exotic chemical substances. It is in these Class B situations that deficiencies of waste treatment methods will initially become the more noticeable.

Keep in mind, too, the continuous and extensive metropolitan-industrial complexes that will develop along these streams; the continuing upsurge in water demands to sustain this growth; and the shrinking distances between outfalls and intakes. Also, there is the mounting reuse factor.

With this composite picture in mind, it is necessary for a reminder that the current parameters of pollution—the 5-day BOD, the bacterial indicator organisms, and the determination of natural organic and inorganic substances, even tastes and odor determinations—all were developed in the early stages of modern sanitary engineering. Prior to World War II, these were reasonably satisfactory yardsticks for the pollution situation of the times. They are still important to the concept of assimilation of pollution by dilution and to measure the self-purification phenomena of streams. But they do fall short—far short—of being effective measurements as reuse of water supplies becomes a dominant factor and as the character of pollution changes.

With respect to this changing pollution, reference is made not only to in-

dustrial sewers, but more pointedly to the changing character of metropolitan waste and to the buildup of chemical pollutants in runoff waters from agricultural and land use practices.

Consider that today such rivers as the Ohio, Delaware, and others are used and reused several times at the dependable low flows. In the years ahead it is reasonable to expect six-time water reuse a common situation in many streams.

Under these conditions, the concept of assimilation of pollution by streams simply breaks down as a major usable factor in the treatment of wastes. Past practice has accepted 90-per cent removal of BOD as being "complete" treatment of municipal waste and sufficient for discharge of the effluent to any stream. But, now it is necessary to call attention to the troublesome conditions below such cities as Chicago, Indianapolis, Columbus, and Dayton.

Consider, also, that under sustained conditions of low flow, the dilution factor available to these cities now varies from 0.14 to 0.65 cfs per 1,000 population. The predicted two per cent annual population increase in these cities will, by 1980, further reduce the dilution factor by 35 to 40 per cent. Compare these factors with the 4 cfs per 1,000 population generally considered essential for primary effluents and 0.6 cfs per 1,000 population for "complete" treatment. And these dilution factors do not anticipate short distance reuse.

The BOD determination alone reflects only part of the picture on the accumulative effects of continuing reuse. Each municipal use brings about a substantial buildup in naturally occurring minerals and a much larger increase in the new exotic substances. These increases alter the environment of the stream, and undoubtedly have profound and as yet ill-defined effects on beneficial stream uses.

Thus, it becomes clear that the term "complete treatment" as now defined, and the percentages of removal of BOD, suspended solids, and bacteria, are inadequate parameters for assessing stream quality in this technological age.

Referring to Table I, there are two additional significant points:

1. The projected populations used for the years 1980 and 2000 are mean figures from special studies by a Congressional committee. It is interesting that these population predictions follow quite well the expected water supply situation. This is just another indication of the direct influence of water resources on industrial development. In other words, industry will go where there is water, and population will build up where there is industry.

2. Although the tabulated data are on the basis of surface water supply, the figures, in a general way, reflect trends in sewered waste loadings. In other words, more water is needed to support more men and machines to produce more sewered pollution to degrade further these same waters. This is a vicious cycle.

Public Health Implications

There are public health implications in the changing volumes and character of pollutants. A few decades back, public health practice focused on the microbiological factors in disease impairments of man. With respect to water supply and sewage disposal, the attention was directed, and properly so, to the problem of controlling germ diseases, largely enteric infections. The brilliant success of this effort certainly needs no amplification. The world leadership of North American water works and sewerage practices stands out in bold relief. In a real sense these achievements, by contributing to the development of modern urban congestion, have in themselves created a new set of problems. The problem of germ diseases will continue—will even be multiplied in the years ahead. But for

the most part, it is now known what to do and how to do it to control these problems.

The health problem now broadens to include this whole array of new type water pollutants—pollutants that have their origin in exotic substances. Even though it is embarrassing, workers in the field simply do not understand the behavior of most of these substances in streams and on water treatment methods. And even less understood are the health-effect potentials—especially from long-term exposure to low concentrations.

To develop the basic intelligence in these fields is going to be extremely difficult. Involved is the matter of combinations of substances, of composites, and of synergisms. In all probability the chronic effects will be subtle, much less definitive than germ diseases, and much more difficult to pin-point—with many cross-influences that need to be equated. The investigator must anticipate, as well as look back. All of this and more, face the modern epidemiologist as he begins to probe these problems. As a matter of fact, there is critical need for a much higher level approach to epidemiology, one attuned to the changing times. There also is need for a complete new look in environmental toxicology. The same advanced electronic computing methods now being used to develop new substances ought also to be used to assess the health effects of these substances.

Actually today, with respect to these exotic substances, the status is about the same as it was at the turn of the century with respect to communicable diseases. The difference today is the complexity and the pace. Doubtless, in time the answers will be found. The question is whether there is the time and whether there is a willingness to commit the money. The probability is that with the rapidity of technological advancement, serious chronic economic effects will be experienced before there is clarification of the chronic health impairments.

Future Plans

It might well be asked, at this stage, just what is being done now to meet these problems looming ahead. In the past few years, real progress has been made in stepping up construction of essential municipal waste treatment plants. For the five years prior to 1956, construction was at a rate of $200 million per year; today the rate is $400 million per year. This is approaching the break-even point in terms of the continuing increase in new sewered population. Considering the World War II backlog, plus the factor of obsolescence, a per annum construction rate above $500 million is needed. Also bear in mind that present construction represents partial treatment and for the most part only primary treatment.

A second difficulty in the current status has been lack of data on actual stream quality. Last year, to start this job, the Public Health Service established a skeleton national water monitoring network. Even though there has been only limited coverage of major streams for a short time, these data reflect some sobering implications. Rather than attempt an interpretation here, it is suggested that review of these data be made as they are published. Particularly important is the information on the buildup of the new exotic chemicals.

The third major difficulty—and the most important of all—has been lack of sufficient research. Modest progress is being made. The national research effort in this field has been stepped up several fold over 1950. Considering that the 1950 level was pitifully small —less than $3 million—the seemingly substantial increase is still woefully inadequate.

Actually, to survive a multi-billion dollar business, such as waste treatment, if competitive, would have to allocate to research a modest percent-

age of its annual gross. For example, in industry the annual research expenditure now is at the $8-billion level to sustain a national gross product of about $450 billion. Realistically, with the increase in volume and complexity of the waste problem which looms ahead, a comparable research effort—about 2 per cent or approximately $40 million per year—must be made in the waste treatment field if the Nation is to have reasonably clean streams within economic practicability. Research is the only salvation to this problem.

Research Needs

To illustrate some areas of research:

1. To assess total pollution, a whole new set of engineering parameters is needed, based on and supported by fundamental scientific facts. Present methods of assessment simply do not reflect the composite pollution situation in streams. These methods are certainly deficient in terms of new substances. For example, exotic chemicals and radioactive wastes, both of which are on the upsurge, are persistent and have ill-defined chronic potentials. Even in terms of biological pollution, the measurements, as commonly used, give an incomplete picture. For example, dissolved oxygen is often based on a few grab samples. To be truly meaningful, as in evaluating oxygen effects on the various stages of fish life, information over a prolonged period is essential. This becomes economical only through automatic continual recording devices. In other words, there is a need to put total stream monitoring on a more scientific basis.

2. Completely new methods of waste treatment should be sought. These should be capable of removing practically any and all types of contaminants and should be flexible enough to permit design to match actual treatment needs. There is a general awareness that there has been no basic scientific breakthrough in this field for over 40 years. Again, the new treatment methods must be in tune with advancing technology, if there is hope to keep up with the oncoming avalanche of problems. Biological processes, as now employed, have been stretched about to their limit. As distinguished from present practices, where the biological processes are essentially naturally occurring and uncontrolled, controlled biological processes do offer some real promise. However, there is still the job of removing contaminants not amenable to biological treatment. It is becoming more and more obvious that there is needed an economical process capable of removing soluble molecules or ions. The waste treatment plants of the future likely will involve combinations of both methods. Moreover, these combinations or designs will probably incorporate valuable salvage potentials, as contrasted with the situation today where salvage is actually more talk than reality. In other words, the time is being approached when it is necessary to take these things out. Salvaging may well become big business.

3. A major focus is needed on evaluation of public health and economic effects. These evaluations are essential for crystallizing public opinion and establishing a basis for national policy and action. In the hustle and bustle of modern American living the average citizen is just too busy—outside his job—to be concerned with much else than his personal health and his pocketbook. He does, however, have tremendous respect for scientific knowledge. There has not been worked out a clear scientific case for water pollution abatement in terms of these two basic interests.

Obviously, to meet such needs, there must be an increasing flow of highly trained engineers and scientists devoted to this field. The infusion of high caliber manpower throughout all

phases of this field is the most promising approach for broadening the national research potential.

Summary

In conclusion, it seems that the Federation, as the national organization closest to this total field, has an opportunity and a public responsibility for crystallizing sound policy recommendations.

Certainly there is a vacuum here to be filled. This profession enjoys an enviable reputation for its achievements. Colleagues earlier in the century resolved their own debates and developed the fundamental concepts that served so well the needs of the times. They reached professional understanding and, for the most part, agreements. The present generation profits from this heritage. But now there are new problems of new magnitudes, new logistics, and new headaches.

Although today there is a great deal of debate among the professionals in this field, for the most part this debate has been carried on without common denominators. It is unfortunate, too, that some of the debate has gone beyond professional circles, and is being misunderstood and misinterpreted in some quarters. This wastes time and costs progress. It seems that the Federation is the logical organization at least for developing common understandings if not agreements on basic points. The Federation could and should become a potent influence in resolving these debates and in developing better answers than so far have been advanced. There must be set forth in bold fashion what needs to be done and in what order of priority.

WATER POLLUTION CONTROL ADVISORY BOARD

At a recent meeting of the Presidentially-appointed Water Pollution Control Advisory Board to the Surgeon General, action was taken by adopting resolutions: (*a*) favoring the extension of the construction grants program for sewage treatment plants, (*b*) recommending a separate budget for water pollution control activities, (*c*) encouraging cooperation between municipalities and regulatory agencies in solving waste problems, (*d*) urging the strengthening of the Federal Water Pollution Control Act, (*e*) recommending the establishment of additional cooperative basic data stations, and (*f*) recommending the expansion of enforcement provisions of the Federal Water Pollution Control Act to include coverage of discharges from Federal installations during the conference and hearing stages of Federal enforcement actions.

One of the new members of the Advisory Board is John Charles Daly, Vice-President of the American Broadcasting Systems. Other members are: John S. Sampson, Chairman of the Nebraska Water Pollution Control Council; Dr. Russell E. Teague, Commissioner of Health for Kentucky, and Secretary of the State's Water Pollution Control Commission; I. T. Bode, former Director of the Missouri Conservation Commission; Anton Hulman, Jr., Chairman of the Indiana Flood Control and Water Resources Commission; Frank E. Long, member of the Wyoming Stream Pollution Control Advisory Council; William Wise, Director of the Connecticut Water Resources Commission; William F. Duckworth, Mayor of Norfolk, Virginia; and Seth Gordon, former Director, California Department of Fish and Game. The Surgeon General, Dr. Leroy E. Burney, is Chairman of the Board.

ACTIVATED SLUDGE MODIFICATIONS *

By Clair N. Sawyer

Associate, Metcalf & Eddy, Engineers, Boston, Mass.

The activated sludge process is now 40-odd years of age, and in many ways its development and range of application resemble that of a man of similar age. Through the years of its early and adolescent development a great deal was learned of the limitations and abilities of the process, and sanitary engineers began to have very fixed ideas as to the boundaries within which the process would operate. In this country, practically every state had definite guide lines established for the design of activated sludge plants and naturally a wide variation existed between states. The highest development along these lines resulted from the pooling of knowledge and experiences by the sanitary engineers of a cluster of states in the Upper Mississippi Valley. This resulted in the development of the so-called "10-States Standards" (1).

The trend to confine the activated sludge process within quite narrow limits served to "trigger" explorations for "holes in the fence" which would allow greater freedom of movement and a wider range of application. The search was intensified by the development of high-rate trickling filters, which threatened for a time to displace the activated sludge process from consideration, in many cases, for economic reasons. Engineers and scientists arose to this challenge and the results of their research are the subject of this paper.

* Presented at the 25th Annual Meeting of the Canadian Institute on Sewage and Sanitation; Quebec City, Quebec; Oct. 20–22, 1958.

Conventional Activated Sludge Process

The activated sludge process was developed at a time when treatment of domestic sewage was the major consideration; consequently it was designed to handle relatively dilute wastes with a preponderance of the organic load in a suspended or colloidal form. Attempts to apply the process to industrial wastes or mixtures of domestic sewage and industrial wastes containing abnormal amounts of soluble and readily oxidizable organic matter often met with failure of the process. Much of this difficulty was associated with a lack of understanding that the process was fundamentally biochemical in character rather than a mere application of physical principles.

Research by numerous investigators in this country, England, Germany, India, and Japan gradually proved to the most skeptical that the activated sludge process was fundamentally biological in character and the last proponents of the "physical theory" disappeared from the scene in the middle forties. By this time the importance of time, temperature, nutrition, and oxygen requirements had been well established. The concepts of food and food-to-organism relationships were brought into focus by the results of research from several laboratories, but the view was sharpened a great deal by the National Research Council reports on sewage treatment at military installations (2) (3).

The present knowledge concerning

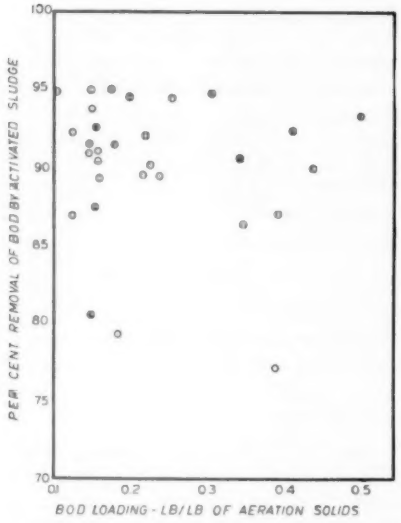

FIGURE 1.—BOD removal vs. BOD loading by conventional activated sludge process.

conventional activated sludge treatment has been summarized very effectively by Haseltine (4). According to this report, as shown in Figure 1, BOD removals in activated sludge units average above 90 per cent at BOD loadings up to 0.3 lb/lb of aeration solids. At loadings between 0.3 and 0.5 lb the efficiency becomes somewhat erratic. He concludes that the maximum loading should not exceed 0.5 lb per lb of aeration solids per day, that large plants may be safely designed at average loadings of 0.3 to 0.4 lb and that small plants which will not receive 24-hr attention should be designed for 0.2- to 0.3-lb loadings.

Although the concept of BOD loading in terms of activated sludge solids is an extremely important one, its application to practice must be seasoned with a knowledge of air requirements and the ability of the sludge separation tanks and return sludge pumping facilities to handle the solids involved. For this reason it is common practice to base design considerations on BOD loading in terms of a unit aeration capacity, usually per 1,000 cu ft. Experience has demonstrated that BOD loadings of 25 to 30 lb/day are about the upper level that can be handled in conventional plants and that a 5-hr detention time is about the minimum that can be safely used, if the aeration solids can be held at about 2,000 mg/l. With a settled sewage having a 5-day BOD of 100 mg/l, a detention time of 5 hr, and aeration solids of 2,000 mg/l, the BOD loading on the aeration tank is 30 lb/1,000 cu ft and the BOD loading/lb of aeration solids is 0.24 lb. Both of these values are within the limits normally accepted as good practice. However, if the BOD of the primary effluent is 200 mg/l, it becomes obvious that the detention time or the aeration solids must be increased as compensation. To increase the aeration period is considered uneconomical in most instances, and attempts to correct the situation by increasing the aeration solids have usually failed because of the development of bulking sludges as a result of insufficient aeration capacity or deterioration of sludge in final separation and return sludge facilities. It seems evident at this time that conventional activated sludge units will serve best when aeration tank loadings can be kept below 35 lb/1,000 cu ft of aeration capacity.

Modifications of the Activated Sludge Process

The limitations of the conventional activated sludge process may be summarized as follows:

1. BOD loadings are limited to about 35 lb/1,000 cu ft. This requires relatively long detention time with resulting high capital investment.
2. A high initial oxygen demand of mixed liquors is encountered.
3. There is a tendency to produce bulking sludge.
4. The process is unable to produce an intermediate quality of effluent.

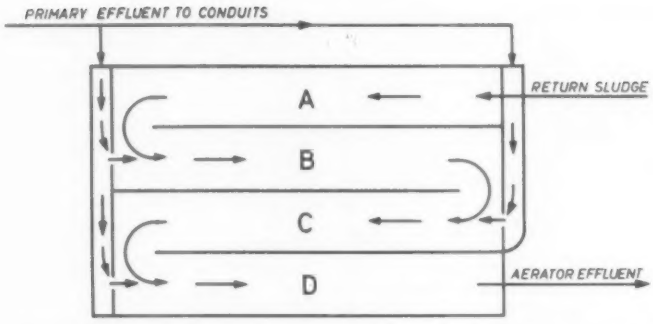

FIGURE 2.—Step aeration process employing a four-pass tank with addition of sewage in B, C, and D passes.

5. High sludge recirculation ratios are required for high BOD wastes.

6. There are high solids loading on final clarifiers.

7. High air requirements accompany the process.

Each of the modifications of the conventional process has been advanced to overcome one or more of these disadvantages. Four rather distinct alternates are in use today which produce complete treatment and one system provides for an intermediate degree of treatment.

Step Aeration

The "step aeration" system of activated sludge treatment was developed by Gould and first applied to plant-scale operation at the Tallmans Island plant in New York City (5). In essence, the process provides for reaeration of returned sludge which allows an opportunity for oxidation of absorbed organic matter and subsequent feeding of sewage in a stepwise manner as shown in Figure 2. In order for the process to be effective, multiple-pass tanks with three or four

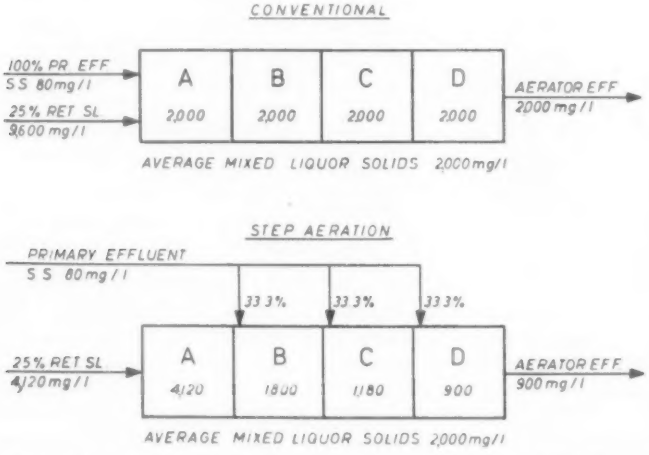

FIGURE 3.—Comparison of solids in return sludge and aeration tank effluent for a given plant operating on conventional and step aeration systems.

passes are necessary. The system depends on maintaining an activated sludge with high absorptive properties so that the organic pollutants can be removed within a relatively short contact period. Step aeration effectively controls the solids loading on final clarifiers. This is demonstrated in Figure 3 which shows a comparison between the solids distribution in a conventional plant with one operated on the step aeration basis with both plants employing 25-per cent return sludge and an average aeration solids of 2,000 mg/l. It will be noted that, although the solids under aeration are the same, the solids in the aerator effluent and in the return sludge in the case of step aeration are less than one-half of those with conventional treatment. This is a major advantage of the modification.

The step aeration process has been used extensively at plants in New York City where the sewage is principally of domestic origin and the results obtained have been excellent (6). Table I shows pertinent information relative to the conditions of operation and Figure 4 shows the quality of effluent produced. It will be noted that the final effluent BOD was less than 6.5 mg/l more than 50 per cent of the time and less than 10 mg/l 85 per cent of the time.

TABLE I.—Summary of Operation* with Step Aeration at the Wards Island Sewage Treatment Plant, New York City, During a 38-Month Period, April 1954 to June 1957

Item	Average	Per Cent Removal
BOD of influent (mg/l)	91	—
BOD of effluent (mg/l)	7.3	92
BOD loading (lb/1,000 cu ft)	42.6	—
Detention time (hr)	2.5	—
Air requirement (cu ft/lb BOD removed)	760	—
Suspended solids of influent (mg/l)	80	—
Suspended solids in effluent (mg/l)	7.2	91

* Secondary units, only.

The step aeration process allows higher BOD loadings and, therefore, shorter detention times, thereby reducing capital investment in aeration tank capacity. It produces activated sludges with good settling properties and, consequently, provides a uniform degree of purification. Provisions have been made for using the process at the

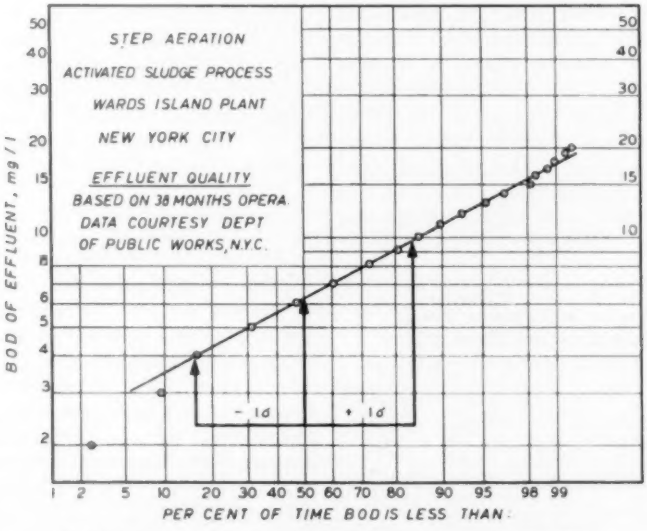

FIGURE 4.—BOD of effluent produced by step aeration.

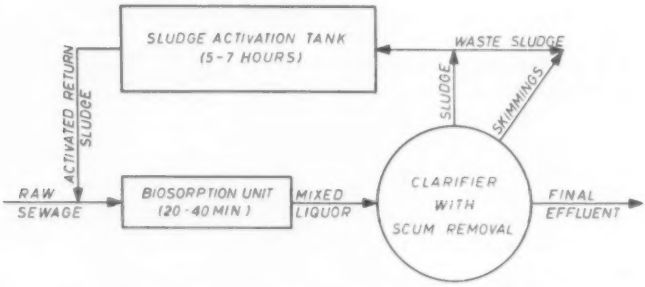

FIGURE 5.—Schematic diagram of biosorption process.

Providence, Rhode Island, Toronto, Ontario, Lima, Ohio, Bergen County Authority, New Jersey, and a few other sewage treatment plants. The results from these installations will be reviewed with a great deal of interest when they are available.

Biosorption

The "biosorption" system of activated sludge treatment was developed at Austin, Texas (7), and in some respects it is quite similar to the step aeration process. It employs a system of reaeration of sludge to restore its purification capacity and a very short, 20- to 40-min., aeration period with unsettled sewage prior to separation of the solids in final clarifiers. A flow diagram is shown in Figure 5. In this system, preliminary settling tanks are eliminated, and separation of sludge and skimmings is accomplished in one set of clarifiers. Following pilot-plant studies at Austin, the entire plant was converted to operate on the biosorption system in 1954 (8). The original aeration tanks designed to handle 6 mgd of sewage as a conventional plant were accommodating from 14 to 16 mgd in 1955, employing the biosorption process, and were producing an effluent of much superior quality. A summary of operating results obtained during 1955 is shown in Table II. The return sludge volume is equal to about 40 per cent of the sewage flow and is kept under aeration from 5 to 7 hr before mixing with raw sewage. On the basis of sewage flows, the effective aeration time, including reaeration, is about three hours. The air requirements have increased from 0.9 cu ft/gal under conventional treatment to 1.6 cu ft with biosorption. The sludge does not compact readily and thickening units are required to obtain concentrations of 2.5-per cent solids. This poses unusual problems in sludge disposal. Lagooning of sludge is practiced at Austin, Texas.

TABLE II.—Summary of Operation with Biosorption at the Austin, Texas, Sewage Treatment Plant, 1955

Item	Average	Per Cent Removal
BOD of influent (mg/l)	307	
BOD of effluent (mg/l)	20	93.4
BOD loading (lb/1,000 cu ft)	144	—
Detention time (hr)	3	—
Air requirement (cu ft/lb BOD removed)	665	—
Suspended solids of influent (mg/l)	226	—
Suspended solids of effluent (mg/l)	18	92.1

Kraus Process

The activated sludge plant at Peoria, Illinois, was originally designed to operate as a conventional plant. This plant received a heavy organic load from industrial sources and operation of the plant was extremely difficult because of the development of a bulking sludge. Kraus (9) (10) developed a system of operation, now commonly known as the "Kraus process," for controlling the sludge index. The system makes operation under high or-

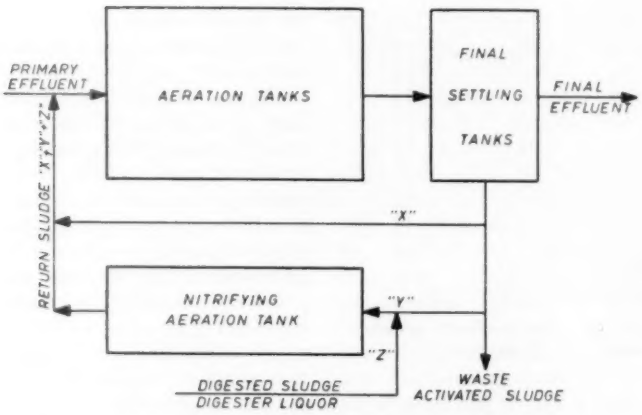

FIGURE 6.—Flow diagram of Kraus modification.

ganic loadings possible. The process involves separate aeration of a mixture of digestion tank supernatant, digested sludge, and some activated sludge to produce a well-nitrified mixture with solids of exceptional settling ability. Addition of this mixture to the return activated sludge serves two purposes. First, it adds weight to the activated sludge and serves as a means of controlling the sludge index. Second, the nitrates present serve as a reserve supply of oxygen and help to maintain aerobic conditions in the aeration tanks under the heavy organic loads imposed, particularly when the sludge is first mixed with the settled sewage. A flow diagram showing the Kraus system is given in Figure 6.

A recent paper by Kraus (11) has given further information on the process and a summary is presented in Table III. It will be noted that BOD loadings as high as 170 lb/day/1,000 cu ft have been treated, with removals in the order of 86 to 90 per cent. The high BOD loadings have exceeded the ability of the conventional aeration system to supply oxygen and the use of a "dual" system of aeration was developed to supply the requirements (11). Figure 7 shows one method of installing the "dual" system of aeration to provide oxygen to meet the increased demand created by the high BOD loadings and appears to be an excellent method of satisfying the requirements. Two aeration systems are required because of the differences in hydrostatic head involved.

Completely Mixed Systems

Those activated sludge plants which employ aeration units in which the in-

TABLE III.—Summary of Operation with Kraus Process at Peoria, Illinois (Experimental 1955)

Item	Test Period		
	A	B	C
Number of days	110	61	10
Aeration tank loading (lb BOD/day/1,000 cu ft)	91.4	135.4	170.3
Aeration period (hr)	2.21	1.61	1.34
Total air (cu ft/lb BOD removed)	663	497	500
BOD removal (per cent)	86.3	86.8	90.1

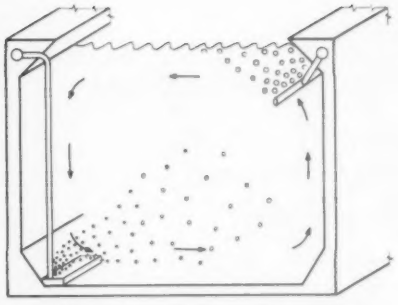

FIGURE 7.—Dual aeration system employed in Kraus process.

fluent sewage is mixed throughout the aeration tank, purposely or otherwise, are called completely mixed systems. The effluent from the aeration unit always contains a small proportion of waste which has had a very short contact time with the activated sludge. Such units are not new, as all package-type plants are designed on this basis and have been in use for over 20 years. Early experience with completely mixed units was erratic. Much of the difficulty was subsequently shown to be the result of inadequate design with respect to aeration capacity, detention time, or sludge handling ability.

Within the past few years there has been a renewal of interest in completely mixed units, particularly for the treatment of high BOD industrial wastes where shock loadings are a particular problem. Dispersal of the load throughout the aeration unit relieves the shock condition and provides for uniform operation. The movement to use completely mixed units has stemmed from several sources, but the papers by McKinney (12) (13) probably best describe the system of treatment. Completely mixed units may operate on a basis of high synthesis of sludge with scheduled wasting of sludge, or they may operate on a basis of complete oxidation of organic waste material, employing the principle of endogenous respiration. The only differences are in the need for sludge-wasting facilities in the former case and a greater air requirement in the latter.

Figure 8 shows the author's conception of an adequate design for a completely mixed unit operating on a high synthesis basis. If the unit were operated on a basis of complete oxidation, there would be no need for the sludge-wasting facilities. Experience has shown that the air requirement when operating on the basis of high synthesis is equal to about 50 per cent of the 5-day BOD. If complete oxidation of the organic matter is necessary, the air requirement is about 150 per cent of the 5-day BOD. Thus, a study of the costs of aerobic destruction of sludge solids versus other methods should precede the choice of system to use.

Modified or High-Rate Activated Sludge Process

All of the variations of the activated sludge process described above are in direct competition with the conventional process since they produce an effluent which is of comparable, or perhaps, superior quality. In many instances, such high-quality effluents are not needed, but something better than that produced by primary treat-

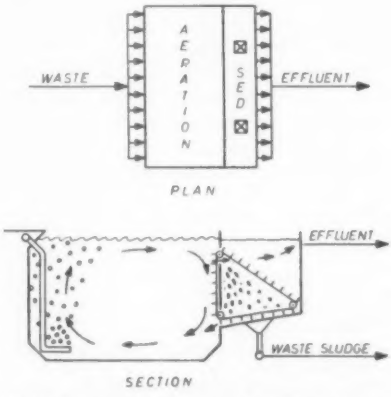

FIGURE 8.—Schematic diagrams of completely mixed activated sludge units.

ment is required. This demand has been satisfied to some extent by single-stage high-rate trickling filters, but large cities have found it more economical to use a modification of the activated sludge process which was developed at New York City by Setter and Edwards (14) (15). The process has been in use at various plants in New York City for the past 15 years and has more recently been applied at Los Angeles, Miami, and Mobile.

The successful operation of high-rate activated sludge units depends on exploitation of the ability of bacteria to reproduce in a geometric manner, more commonly called the log growth phase. It has been well established that bacterial growth is accompanied by a demand for oxygen and food which is proportional to the growth. The latter results in a conversion of soluble organic matter to cell tissue and is really the fundamental basis by which activated sludge purifies liquid wastes. Many years ago Burtle and Buswell (16), while studying the oxygen demand of sewage, found the demand to vary widely over a period of 10 or more hours. A typical demand curve is shown in Figure 9. In light of modern knowledge, this curve shows that bacterial reproduction was extremely rapid from the second to the sixth hour and that by the end of the sixth hour the soluble food supply had been largely converted to cell tissue. Removal of bacterial growths at this point would result in a high degree of purification. Experiences with plain aeration have shown that relatively poor removals of BOD result because the bacterial growths will not agglomerate and settle. Plain aeration also suffers from a lag period preceding the log growth phase.

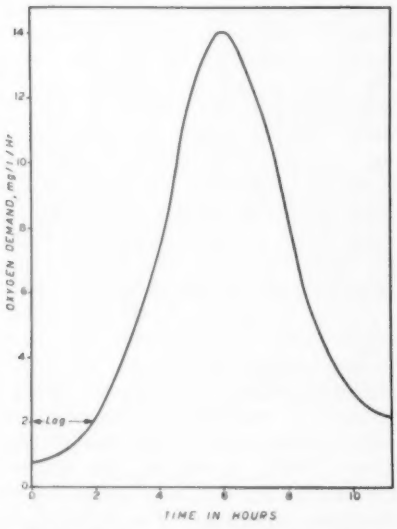

FIGURE 9.—The oxygen demand of domestic sewage.

The high-rate process attempts to overcome the limitations of plain aeration by the use of a small amount of return sludge which acts as an inoculum. The inoculum has three beneficial effects:

1. It reduces the lag period.
2. It shortens the period of the log growth phase.
3. It provides surfaces for agglomeration of new bacterial cells.

As a result of these effects, the entire purification process is accomplished within a period of 2 to 3 hours rather than the 10 or more needed when plain aeration is used. To assure successful operation, it is imperative that the return sludge be in a highly active form to overcome the lag period. Temperature is an important factor, and determines to a large extent the amount of return sludge needed. As a rule, the rate of sludge removal from the final clarifiers seldom need be more than 10 per cent of the sewage flow. About one-half of this will be needed for inoculum in the aeration tank and one-half must be wasted. These factors are important considerations in design.

The high-rate process does not produce highly clarified effluents; therefore, the BOD and suspended solids

in the effluent are appreciably higher than encountered in other systems of activated sludge treatment. Because of this, percentage removals lose their significance unless influent characteristics are mentioned. According to Torpey and Chasick (6), treatment of settled sewage at New York City has resulted in final effluents with a BOD in the range of 38 to 64 mg/l, or 57- to 71-per cent removals, and treatment of raw sewage without primary settling has yielded final effluents with a BOD in the range of 32 to 59 mg/l, or 63- to 76-per cent removals.

Personal acquaintance with the operation of the high-rate activated sludge processes at Los Angeles, Miami, and Mobile reveals several interesting facts. All three plants handle sewage which is substantially stronger than that involved at New York City and at much higher temperatures. The Mobile plant has just recently started operations and insufficient data are available for analysis. A large amount of data is available from both Los Angeles and Miami, and that described here is given with permission. The Los Angeles plant treats settled sewage while the Miami plant treats raw sewage. Both plants have excellent analytical control; consequently the results should be of real value.

Hyperion

The Hyperion plant at Los Angeles has been in operation for several years. It was designed on the basis of New York City experience, and, as a result of much higher temperatures and a stronger sewage, a number of modifications were required (17). These modifications were essentially complete by April of 1956 and the operating results during the bathing seasons (May–October) of 1956, 1957, and May and June of 1958 have been used to illustrate the results that have been obtained.

TABLE IV.—Summary of Operation* with High-Rate or Modified Activated Sludge at Hyperion Plant, Los Angeles (14 Months Summer Season Operation) (May to November 1956 and 1957 and May to June 1958)

Item	Average	Per Cent Removal
BOD of influent (mg/l)	206	—
BOD of effluent (mg/l)	45	78.2
BOD loading (lb/1,000 cu ft)	103	—
Detention time (hr)	3.0	—
Air requirements (cu ft/lb BOD removed)	620	—
Suspended solids of influent (mg/l)	214	—
Suspended solids in effluent (mg/l)	60	72.2
Chlorine demand of influent (mg/l)	30	—
Chlorine demand of effluent (mg/l)	3	90.0
Ether soluble material in influent (mg/l)†	36	—
Ether soluble material in effluent (mg/l)†	5	86.0

* In secondary units, only.
† 1957 and 1958.

Table IV summarizes the results produced by the high-rate activated sludge process at Hyperion during 14 months of summer-season operation. During this period the aeration tanks were loaded at a rate of 103 lb of BOD/day/1,000 cu ft and BOD and suspended solids removals averaged 78.2 and 72.2 per cent, respectively, and grease removals averaged 86 per cent. At the same time the chlorine demand was reduced from 30 to 3 mg/l, a reduction of 90 per cent. The latter is an item of much economic importance at Los Angeles as the effluent must be disinfected to maintain the waters in Santa Monica Bay in a satisfactory condition for bathing. Each mg/l of chlorine demand destroyed results in a saving of about 1.1 tons of chlorine per day for the flows involved at the Hyperion plant.

One of the questions which has been asked about the high-rate activated sludge process concerns its ability to produce an effluent of uniform quality. In order to answer this question, the daily BOD values of the effluent produced at the Hyperion plant during the 14-month period were subjected to statistical analysis. The results are given in the form of a probability curve in Figure 10. These data show

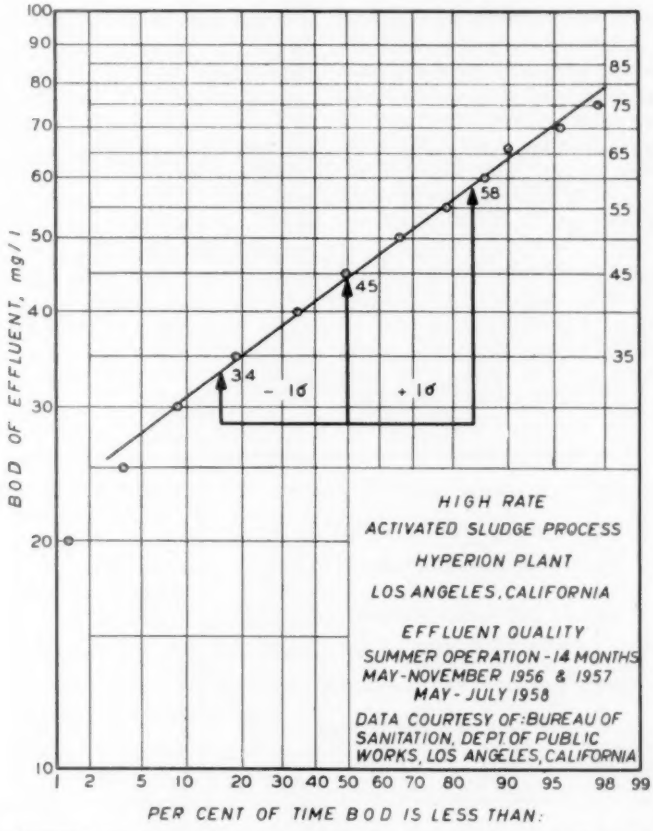

FIGURE 10.—Probability curve of BOD in final effluent at Hyperion treatment plant, Los Angeles, California.

that the average BOD is 45 mg/l and the normal expectancy is for the BOD to fall within the range of 34 to 58 mg/l. Since the data produce a straight line on a logarithmic probability plot, this proves the process is normal in behavior.

Miami

The Miami sewage treatment plant was designed to treat raw sewage by the high-rate activated sludge process. Because of low sewage flows during initial operation, an attempt was made to operate on the conventional basis but the process was difficult to control. High-rate treatment has been employed since December 1957, and the results of the first eight months of operation are given in Table V. The

TABLE V.—Summary of Operation* with High-Rate or Modified Activated Sludge at Miami, Florida (January to August 1958)

Item	Average	Per Cent Removal
BOD of raw sewage (mg/l)	140	—
BOD of effluent (mg/l)	45	68.0
BOD loading (lb/1,000 cu ft)	63	—
Detention time (hr)	3.3	—
Air requirement (cu ft/lb BOD removed)	975	—
Suspended solids, raw sewage (mg/l)	149	—
Suspended solids in effluent (mg/l)	44	70.5

* Includes six months when unlimited septic tank discharges were accepted.

performance of the plant was affected to some extent during the first six months of the period by the acceptance of a large volume of septic tank cleanings. In spite of this, the average BOD and suspended solids of the effluent were 45 mg/l and 44 mg/l, respectively. The air requirement has averaged 975 cu ft/lb of BOD removed.

The daily BOD data of the Miami plant have been analyzed statistically as shown in Figure 11. Because of the suspected influence of the septic tank cleanings, the data with and without septic tank sludge have been treated separately. It was found that the BOD of the effluent with septic tank sludge averaged 37 mg/l and the normal expectancy was for the BOD to fall between 24 and 57 mg/l. Without septic tank sludge, the effluent BOD averaged 24 mg/l and the normal range was between 18 and 32 mg/l. During the latter period, BOD removals averaged 77.4 per cent. The manner in which these data plot on logarithmic probability charts proves again that the high-rate process can be operated in a highly reliable manner once the principles are understood and recognized.

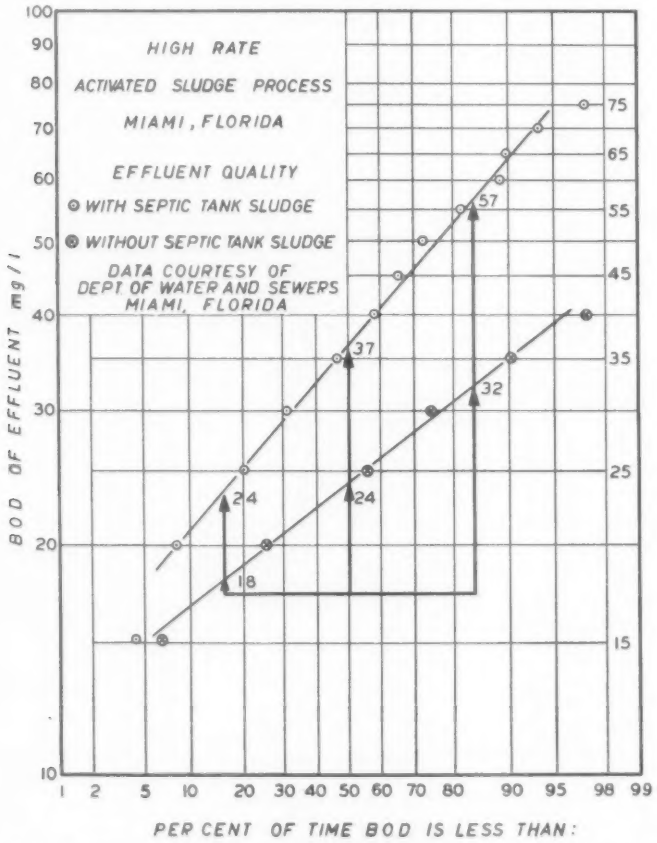

FIGURE 11.—Probability curve of BOD in final effluent at Miami plant.

Sludge Separation Units

One of the major developments of the activated sludge process has been a growing realization that sludge separation and its rapid return to the aeration units is an integral and important part of the process. This prevents the deterioration of sludges that occurs in the absence of oxygen and is of particular importance in all modifications of the process in which sludges which are highly burdened with unstable organic matter are sent to the final clarifiers. Modern designs recognize the problems imposed by density currents (18) and the trend is to design wide, short, rectangular-type units. Circular clarifiers are being designed to allow peripheral feed rather than center feed (19). In addition, clarifier mechanisms are available which remove sludges from the point of deposition rather than transporting it long distances by plow or scraper-type mechanisms whose rate of travel must be severely limited.

Aeration Facilities

The increased BOD loadings on aeration facilities have increased the air requirements in almost direct proportion to the load. Standard aeration facilities have been taxed to the limit to satisfy the demands. New developments such as turbine or rotor type mechanical aerators (20) have provided one answer to the problem. Another answer has been provided in the newer knowledge concerning the significance of coarse bubble aeration (21). A still different approach has been that proposed by Kraus (11), who recommends the use of a dual system employing both large and small bubble aeration.

Conclusions

A wide variety of modifications of the activated sludge process is currently available for the treatment of sewage and industrial wastes. In order to utilize the most appropriate modification for a given waste, the designing engineer must make a careful evaluation of many factors involved. The major items are:

1. BOD of the waste involved.
2. Space available.
3. Temperature of the waste.
4. Power costs.
5. Quality of effluent required.
6. Sludge disposal.
7. Relative importance of capital to operating costs.
8. Quality of operation and labor costs.

Acknowledgments

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UTILITIES IN THE CENSUS

Some 180 million people will be counted in the 18th decennial census of the United States during the month of April. The 1960 census will include a number of inquiries about dwellings. Among these inquiries will be questions about sewage disposal (for areas outside cities) and source of water. These questions will be asked at one in four households, therefore will provide a highly representative sampling.

There has been considerable interest in obtaining this information from the census and it is expected to be of widespread help to many phases of these utilities.

LOAD AND EFFICIENCY OF TRICKLING FILTERS *

By K. L. Schulze

Assistant Professor, Department of Civil Engineering Michigan State University, East Lansing, Mich.

In a previous publication (1) an experimental trickling filter has been described, which uses vertically suspended wire grids as support for the microbial growth. Investigation of the biological film showed that its thickness was related to the strength of the waste handled. With dairy waste having a BOD from 200 to 2,000 mg/l the film developed to a maximum thickness of 6 to 8 mm on each side of the screen. With municipal sewage having a BOD of about 100 mg/l the maximum film thickness was 1 to 2 mm. Since oxygen is supplied by diffusion through the surface of those films the existence of anaerobic zones was to be expected in thick films. Microscopic sections demonstrated the presence of aerobic and anaerobic layers whenever the depth of the film developed to more than 2 mm.

In addition to these biological observations, data on the efficiency of the filter under various hydraulic and organic loads were collected for a period of 18 months. It is the purpose of this paper to present these data and to discuss the relationship between hydraulic load, organic load, and efficiency in trickling filters.

* Presented at the 32nd Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Dallas, Tex., Oct. 12–15, 1959.

Experimental Procedure

Design and operation of the filter have been described earlier (1). For

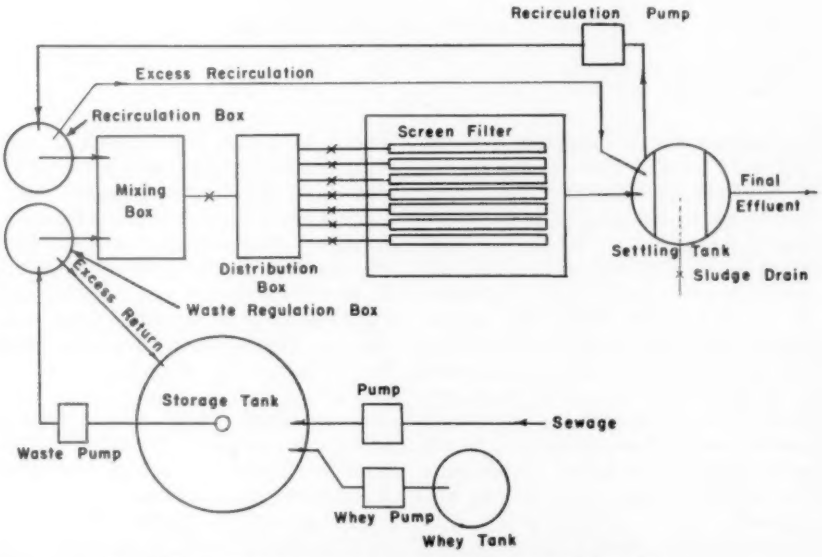

FIGURE 1.—Flow diagram for experimental screen trickling filter.

TABLE 1.—Data From Series 1, Where Hydraulic Load was 5.5 mgd/acre and Duration of Run was 67 Days

Data Group	x_i*	y_i†	Efficiency (per cent)	Data Group	x_i*	y_i†	Efficiency (per cent)
1	0.47	0.36	77	4	2.52	1.81	72
	0.53	0.38	72		2.60	1.61	62
	0.58	0.42	72		2.64	2.11	80
	0.68	0.53	78		2.74	2.08	76
	0.68	0.49	72		2.85	2.00	70
	0.70	0.54	77		2.85	2.11	74
	0.70	0.51	73		2.90	2.03	70
	0.71	0.54	76		2.92	2.13	73
Avg	0.63	0.47	74.6	Avg	2.75	1.98	72.1
2	0.71	0.53	75	5	2.98	2.26	76
	0.76	0.57	75		3.00	2.19	73
	0.76	0.58	77		3.10	2.17	70
	0.78	0.57	73		3.24	2.49	77
	0.79	0.58	73		3.30	2.48	75
	0.81	0.60	74		3.30	2.41	73
	0.83	0.65	78		3.30	2.44	74
	0.83	0.60	72		3.33	2.20	66
Avg	0.78	0.58	74.6	Avg	3.19	2.33	73.0
3	0.86	0.69	80	6	3.40	2.55	75
	0.89	0.66	74		3.42	2.57	75
	0.93	0.62	67		3.42	2.63	77
	1.65	1.29	78		3.46	2.60	75
	2.18	1.31	60		3.46	2.60	75
	2.25	1.62	72		3.52	2.60	74
	2.26	1.76	78		3.70	2.89	78
	2.50	1.78	71		3.95	3.08	78
					4.60	3.77	82
Avg	1.69	1.23	72.5	Avg	3.66	2.80	76.6

* Applied load, lb BOD/day/cu yd.
† Removed load, lb BOD/day/cu yd.

convenience the flow diagram is shown in Figure 1. The filter itself consisted of 7 vertically suspended ½-in. mesh wire screens, arranged in parallel and spaced 2 in. apart. The screens, each 3 ft wide and 6 ft long, were made from hardware cloth and occupied a volume of 18 cu ft. The horizontal surface area of the filter model was 3 sq ft so that 69 gpd of waste flow corresponded to a hydraulic load of 1 mgd/acre. Since it was difficult to distribute smaller waste flows evenly over the entire width of the screen, a minimum flow of 800 ml/min, corresponding to a hydraulic load of 4.4 mgd/acre had to be maintained. Even under these conditions not all of the screen surface was used. At higher flow rates this difficulty diminished so that practically all strands of the screens received waste and were covered with biological growth. Sampling of incoming waste and final effluent was accomplished by plastic dippers revolving at 1 rpm. Since all experiments were conducted at continuous, uniform flow rates, provisions for proportionate sampling were not needed. Composite samples for duplicate standard BOD determinations were collected daily. Settled sewage from the East Lansing sewage treatment plant served as a basic feed to the filter.

For experiments on the effect of increasing organic load the pumping rate was kept constant and increasing

amounts of whey were added to the settled sewage. For experiments on the effect of increasing hydraulic load, settled sewage alone was used and the pumping rate was increased stepwise. The filter was operated as a single pass unit. All data on efficiency are related to per cent BOD removal effected through the filter and final settling tank. For statistical analysis the procedures outlined by Youden (2) were used.

Increasing Organic Load Tests

Series 1

In series 1 the screen filter was operated 67 days at an average flow of 379 gpd, corresponding to a hydraulic load of 5.5 mgd/acre. During this period 5 to 10 gal of whey were added daily to the settled sewage. Data from this run were arranged according to increasing organic load and divided into six groups of 8 data each. Since there were 49 data available, the last group contains 9 data. The data are presented in Table I. The first column (x_1) shows the applied load in pounds BOD per cubic yard per day, the second column (y_1) shows the pounds BOD removed per cubic yard per day through the filter and final settling tank, and the third column indicates the efficiency (b_1) in per cent BOD removal.

The averages of the six groups were then plotted in curve *A*, Figure 2. In spite of the fact that the applied BOD load increased from 0.47 to 4.6 lb/day/cu yd it can be seen that the data fit a straight line relationship with the line passing through the origin. The curve representing the efficiency was therefore computed according to the formula $y_1 = b_1 x_1$ where

y_1 = lb BOD removed per cubic yard per day,
x_1 = lb BOD applied per cubic yard per day, and
b_1 = slope, or $b_1 \times 100$ = per cent efficiency.

Using the method of least squares the slope can then be computed according to the equation $b_1 = \frac{\Sigma(x_1 y_1)}{\Sigma(x_1^2)} = 0.744$.

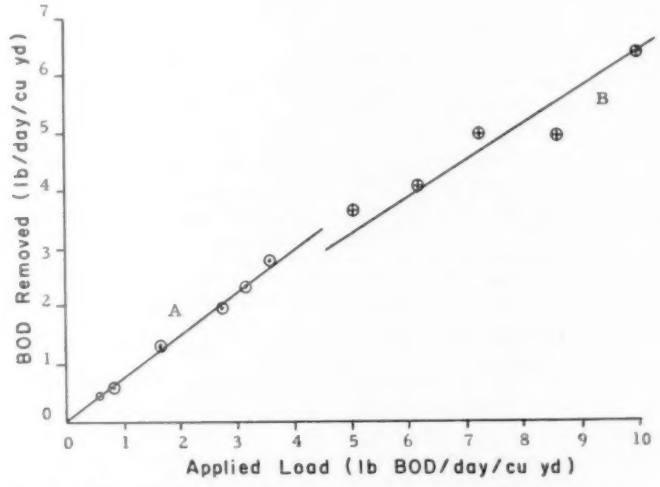

FIGURE 2.—Relationship between organic load and efficiency. Curve *A* is Series 1 with a hydraulic load of 5.5 mgd/acre; Curve *B* is Series 2 with a hydraulic load of 8.1 mgd/acre.

This value corresponds to an efficiency of 74.4 per cent. The standard deviation S_1 for single measurement was ± 4.17 per cent. The data show that at a hydraulic load of 5.5 mgd/acre the filter efficiency was 74.4 per cent and was independent of the organic load within the range of 0.5 to 4.5 lb BOD/day/cu yd.

Series 2

In series 2 the filter was operated for 26 days at an average flow of 562 gpd, corresponding to a hydraulic load of 8.1 mgd/acre. The addition of whey to the settled sewage was increased to 10 to 20 gpd. The BOD of the incoming waste mixture ranged from 600 to 1,560 mg/l and the organic load from 4.5 to 10.9 lb BOD/day/cu yd.

The 25 data from this series were again arranged according to increasing organic load and divided into five groups of 5 data each as shown in Table II. The averages of the applied load (x_2) were then plotted against the average BOD removed (y_2) the same way as in series 1. As shown in curve *B*, Figure 2, the data appear to fit a straight line, although at a much higher degree of scatter than curve *A*. The average efficiency was 66.94 per cent with a standard deviation of single measurement of ± 7.24 per cent. Using the method of least squares the data could be fitted to an equation: $y_2 = a + b_2 x$, where $a = 0.89$ and $b_2 = 0.543$. The line would then not pass through the origin but have an intercept $a = 0.89$ lb BOD removed at an applied load of zero. To resolve the question as to whether it is justified to let the line pass through the origin or whether the intercept, a, should be used, a statistical F-test measuring and comparing the fit of the lines under both conditions was used. The variance for the line going through the origin, $y_2 = 0.656\ x_2$ is $\frac{S'}{n-1} = \frac{7.80}{24} = 0.325$. The variance for the line with intercept, $y_2 = 0.89 + 0.542\ x_2$ is $\frac{S}{n-2} = \frac{6.71}{23} = 0.292$.

TABLE II.—Data From Series 2, Where Hydraulic Load Was 8.1 mgd/acre and Duration of Run was 26 Days

Data Group	x_2*	y_2†	Efficiency (per cent)
1	4.50	3.24	72
	4.80	3.22	67
	5.05	3.94	78
	5.40	4.20	78
	5.45	3.87	71
Avg	5.04	3.70	73.4
2	5.55	3.66	66
	5.95	3.81	64
	6.20	4.40	71
	6.45	4.32	67
	6.60	4.36	66
Avg	6.15	4.11	66.5
3	6.60	4.82	72
	7.00	4.20	70
	7.40	5.33	72
	7.40	5.26	71
	5.45	4.92	66
Avg	7.17	5.05	70.2
4	8.25	4.54	55
	8.65	6.57	76
	8.70	6.35	50
	8.75	4.99	57
	8.75	4.81	55
Avg	8.62	5.05	58.6
5	8.90	6.14	69
	9.45	6.43	67
	10.10	6.26	62
	10.40	7.49	72
	10.90	6.54	60
Avg	9.95	6.57	66.0

* Applied load, lb BOD/day/cu yd.
† Removed load, lb BOD/day/cu yd.

The smaller variance indicates that the line with intercept provides a better fit. This was to be expected, since the line with intercept was the result of the application of the least squares method. But the measure of the improvement is given by the F-ratio,

where $F = \dfrac{S' - S}{S/n - 2} = 3.73$ for 1 and 23 degrees of freedom.

The 5-per cent critical value for F with 1 and 23 degrees of freedom is 4.28 and has not been reached. Therefore there is insufficient evidence to maintain that the intercept differs from zero more than can be accounted for by the variation in the experimental data. The assumption that curve B, series 2, passes through the origin is justified and b_2 can be computed in the same manner as b_1. Accordingly, curve B in Figure 2 was drawn by using $b_2 = 0.656$.

The data therefore show that at a hydraulic load of 8.1 mgd/acre the efficiency of the filter was $b_2 = 0.656$ or 65.6 per cent and was independent of the organic load from 4.5 to 10.9 lb BOD/day/cu yd.

Significance of Test Series

Taken together series 1 and 2 cover a range in organic load from 0.47 to 10.9 lb BOD/day/cu yd or from 17.4 to 403 lb BOD/day/1,000 cu ft. In both cases it was demonstrated that the efficiency measured as per cent BOD removed was not decreased by increasing organic loads.

A difference in efficiency was established, though, for the two hydraulic loads used, 5.5 and 8.1 mgd/acre. The corresponding efficiencies were 74.4 and 65.6 per cent. An attempt was made to decide whether the decrease of 8.8 per cent in efficiency at the higher hydraulic load was statistically significant or due to chance fluctuation. The t-Test was used for this purpose and indicated that the difference in efficiencies due to the different hydraulic loads was statistically significant.

Additional evidence for the concept that the efficiency at a given hydraulic load is not affected by organic load was provided by comparison of three different runs made at nearly the same average hydraulic load but at different average organic loads. The average organic loads ranged from 0.78 lb BOD/day/cu yd for group A to 3.09 lb BOD/day/cu yd for group C. The efficiencies were compared by the t-Test and the results are shown in Table III. For all three group combinations the t-values did not reach the 5-per cent critical value. The changes in efficiency were therefore due to chance fluctuations and the increase in organic load had no significant effect as far as efficiency was concerned. The three groups could be pooled and it could be stated that the average efficiency of the screen filter was 73.4 per cent for all three runs, regardless of the differences in organic load.

From the statistical analysis it is evident that the efficiency of the screen trickling filter was independent of the organic load up to 10.9 lb BOD/day/cu yd, but decreased as soon as the hydraulic load was increased. It appeared that the controlling factor for efficiency was the hydraulic load. If this was true then it should be possible

TABLE III.—Comparison of Three Sets of Data at the Same Hydraulic Load

Groups	Avg Hydr. Load (mgd./acre)	Avg BOD Load (lb/day/cu yd)	Avg Efficiency (per cent BOD removed)	No. of Data	Groups Compared	Degrees of Freedom	t	5 Per Cent Crit. Value for t
A '56 (20 days)	5.71	0.78	74.3	15	A & B	23	0.25	2.07
B '57 (10 days)	5.78	2.90	71.4	10	B & C	29	1.85	2.05
C '56 (22 days)	5.26	3.09	74.6	21	A & C	34	1.59	2.03

TABLE IV.—Effect of Hydraulic Load

Group	Avg Hydr. Load (mgd/acre)	Avg BOD Load (lb/day/cu yd)	Avg Efficiency (per cent)	No. of Data	Stand. Deviation	Groups Compared	Degree of Freedom	t	1 Per Cent Crit. Value for t
1	4.9	0.44	81.0	17	±5.56	1 & 2	64	5.39	2.65
2	5.5	2.15	74.0	49	±4.17	2 & 3	72	5.23	2.53
3	8.1	7.39	64.0	25	±7.24	3 & 4	42	3.84	2.70
4	10.5	0.98	59.7	19	±4.74	4 & 5	37	6.05	2.72
5	14.5	1.47	50.0	20	±5.24	5 & 6	37	6.83	2.72
6	21.7	2.16	38.9	19	±4.85	6 & 7	29	6.63	2.76
7	30.0	2.76	25.8	12	±6.06	—	—	—	—

to compare filter efficiencies at various hydraulic loads regardless of the organic load applied in each case, as long as this organic load did not exceed 11 lb BOD/day/cu yd.

Data were therefore grouped according to increased hydraulic loads and the average efficiencies compared by the t-Test.

Increasing Hydraulic Load Tests

The screen filter was operated at 7 different hydraulic loads from 4.9 to 30 mgd/acre during the entire length of the experimental period. The results of these seven runs are listed in Table IV.

The data show that the average efficiency decreased from 81.0 per cent at 4.9 mgd/acre to 25.8 per cent at 30 mgd/acre. Comparison of the averages by the t-Test resulted in values for t which were in each case much higher than the critical values at the 1-per cent probability level. The differences in average efficiencies were therefore statistically highly significant. This was true even though the average organic loads varied from 0.44 to 7.39 lb BOD/day/cu yd.

Efficiency and Hydraulic Load

The relationship between efficiency and hydraulic load is shown graphically

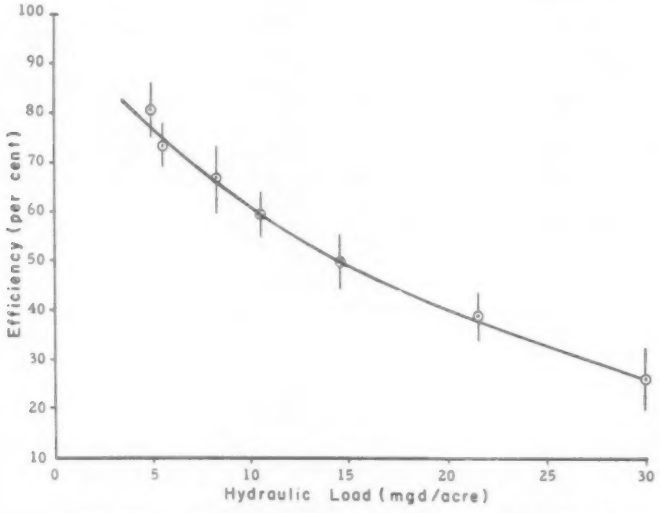

FIGURE 3.—Relationship between hydraulic load and efficiency. (Vertical lines indicate standard deviation).

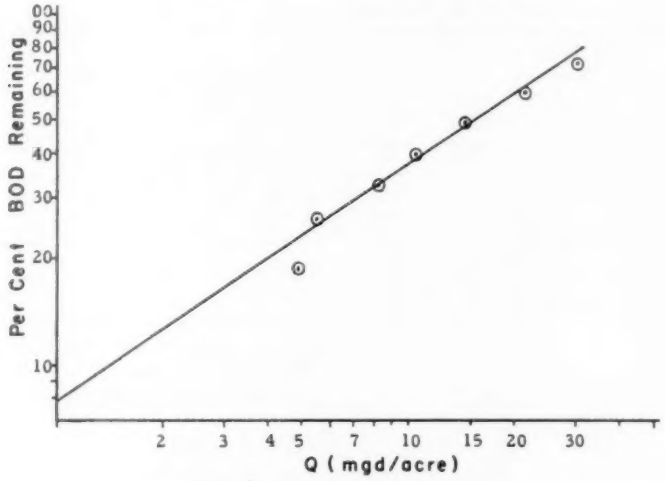

FIGURE 4.—Performance of screen filter.

in Figure 3 where the average efficiencies, groups 1 to 7, have been plotted together with their respective standard deviations.

The curve shows that there is no apparent linear relationship between hydraulic load and efficiency. Figure 4 shows that a log plot approximates a straight line. With the exception of the first point the data from Table II fitted this line very well. The curve can be represented by the parabolic equation

$$\frac{L_e}{L_i} = aQ^c \quad \ldots\ldots\ldots\ldots (1)$$

Where

L_e = final effluent BOD (mg/l),
L_i = BOD of flow to the filter (mg/l),
Q = hydraulic load (mgd/acre),
c = constant, and
a = intercept at $Q = 1$.

The constant derived from the graph was $c = 0.67$ and the intercept was $a = 0.079$ so that

$$\frac{L_e}{L_i} = 0.079Q^{0.67} \quad \ldots\ldots\ldots\ldots (1a)$$

This means that the fraction of BOD remaining is proportional to the hydraulic load Q to the 0.67 power. The constant 0.67 duplicates the two-thirds power of Q used by Howland (3) and Bloodgood, Teletzke, and Pohland (4) in computing the contact time for trickling filter models at various flow rates. According to Howland, contact time is directly proportional to depth of the filter and inversely proportional to the two-thirds power of the hydraulic load:

$$t = \frac{D}{Q^{\frac{1}{2}}} \quad \ldots\ldots\ldots\ldots (2)$$

where

t = factor representing contact time, and
D = depth of filter in feet.

If it is assumed that the fraction of BOD remaining is directly related to contact time, then this could be expressed by the equation

$$\frac{L_e}{L_i} = e^{-kt} \quad \ldots\ldots\ldots\ldots (3)$$

where t would be replaced according to Equation 2 so that

$$\frac{L_e}{L_i} = e^{-kD/Q^{\frac{1}{2}}} \quad \ldots\ldots\ldots\ldots (4)$$

TABLE V.—Relationship Between Hydraulic Load and Per Cent BOD Remaining for a Filter Depth of Six Feet

Q (mgd/acre)	Avg Temp. (°C)	t	K	Theor. Per Cent BOD Remaining	Exp. Per Cent BOD Remaining
4.9	20.6	2.07	0.33	23.9	19.0
5.5	15.8	1.92	0.33	26.5	26.0
8.2	14.1	1.47	0.32	36.2	33.0
10.5	21.3	1.24	0.31	42.5	40.3
14.5	22.1	1.00	0.28	50.1	50.0
21.7	21.4	0.76	0.25	59.0	61.1
30.0	20.2	0.61	0.22	65.6	74.2

or

$$\frac{L_e}{L_i} = 10^{-KD/Q^{\frac{1}{3}}} \quad \ldots\ldots (5)$$

where

K = constant, and
$k = 2.303K$.

In logarithmic form,

$$\log \frac{L_e}{L_i} = -K \frac{D}{Q^{\frac{1}{3}}} \quad \ldots\ldots (6)$$

and

$$K = \frac{\log \dfrac{L_i}{L_e}}{t} \quad \ldots\ldots (7)$$

A plot of $\log \dfrac{L_e}{L_i}$, the fraction of BOD remaining, against the time factor t should then result in a straight line with the slope K. The experimental data presented in Table IV were used to test the value of the formulations given above. The results are shown in Table V and Figure 5.

The experimental K values vary between 0.22 and 0.33. For the curve in Figure 5 a value of $K = 0.30$ was used and it can be seen that the experimental data fit the curve reasonably well, with the exception of the lowest and the highest hydraulic load.

Effect of Depth

It appears therefore that the efficiency of the experimental filter for any given depth and hydraulic load can be computed by

$$\frac{L_e}{L_i} = 10^{-0.3D/Q^{\frac{1}{3}}} \quad \ldots\ldots (8)$$

The graph demonstrates that at $t = 0$, Q infinite, the BOD removal is zero, and that 100-per cent BOD removal is approached at $t = \infty$, hydraulic load zero.

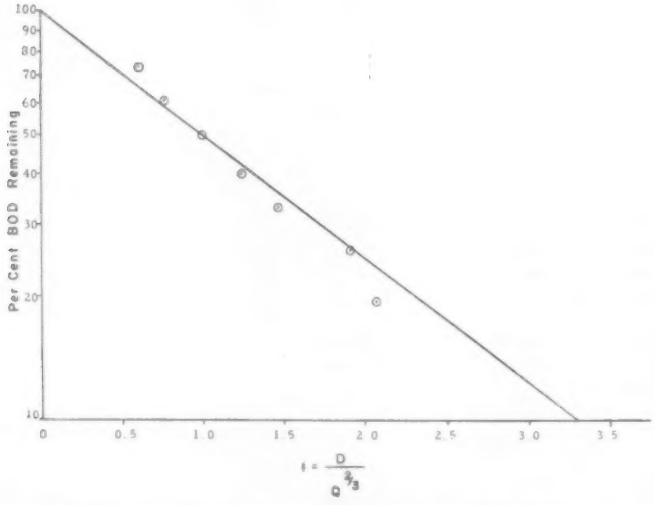

FIGURE 5.—Effect of time on performance of screen filter.

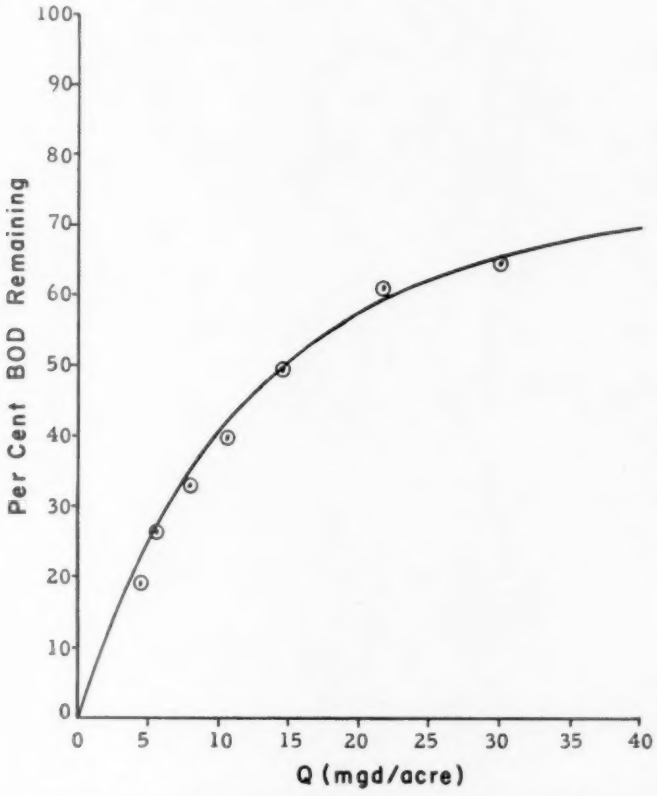

FIGURE 6.—Effect of hydraulic load on screen filter performance for a six-foot filter with K of 0.3.

Equation 5 is similar to the one used by Velz (5) to formulate the basic relationship between filter depth and rate of BOD removal:

$$\frac{L_D}{L} = 10^{-K_1 D} \quad \ldots\ldots\ldots (9)$$

Where

L_D = removable BOD remaining at depth D (mg/l),
L = removable BOD in incoming flow (mg/l), and
K_1 = constant = 0.175 for low rate filters.

According to this concept the efficiency of a trickling filter of a given depth is a constant. Now it appears that this is true only for a given hydraulic load and that Velz's constant K_1 consists of two factors, namely K and Q^1:

$$K_1 = \frac{K}{Q^1} \quad \ldots\ldots\ldots (9a)$$

where $K = 0.30$, according to the data presented here. A value of $K_1 = 0.175$ would then correspond to a hydraulic load of $Q^1 = 1.7143$ and $Q = 2.25$ mgd/acre, which is in agreement with the range of hydraulic loads commonly used for standard filters.

Equation 7 now makes it possible to compute the effect of depth at any given hydraulic load, or the effect of hydraulic load at any given filter depth. This is demonstrated in Figure

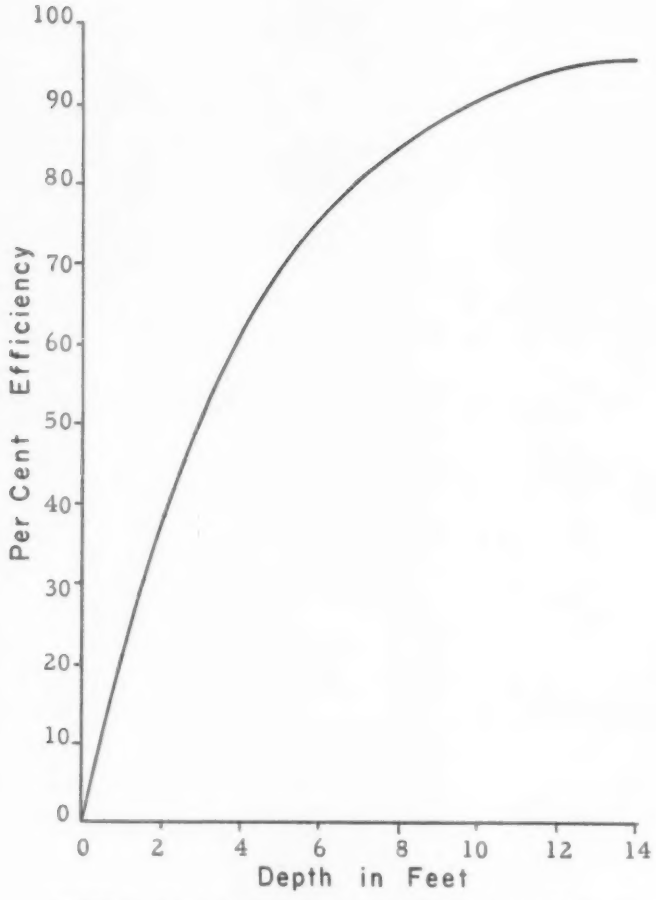

FIGURE 7.—Effect of filter depth at a hydraulic load of 5 mgd/acre.

6 where hydraulic load Q has been plotted against per cent BOD remaining according to Equation 7 at $D = 6$ ft. The experimental data fit the theoretical curve well. In Figure 7 a theoretical curve has been plotted to show the effect of filter depth at a hydraulic load of 5 mgd/acre. The curve is of the same type as those shown by Grantham *et al.* (6) and many other experimental investigators.

There are two other concepts involved in this depth—BOD removal relationship. One of these is the idea that not all of the applied BOD can be removed, even theoretically. The other concept is that of the limiting organic load. For standard filters it has been assumed (5) that the removable BOD is equal to 90 per cent of the applied BOD. There appears to be no reason to maintain this concept because theoretically with contact time approaching infinity the fraction of applied BOD remaining should approach zero. L_r is therefore used here to denote actual applied BOD. The limiting organic load was assumed to be about 3 lb BOD/day/cu yd (5). From the curve in Figure 2 it can be seen that the

efficiency of the experimental filter at a given hydraulic load was constant up to organic loads of approximately 11 lb BOD/day/cu yd. Rigbi *et al.* (7) showed that the same held true for full-scale trickling filters up to 8 lb BOD/day/cu yd. Trebler *et al.* (8) using dairy waste, loaded their experimental filters up to 25 lb BOD/day/cu yd and the efficiency did not appear to decline. The efficiency in this particular instance was only 35 per cent. But this was obtained at a hydraulic load of 28 mgd/acre and according to the curve shown in Figure 6, 65 per cent BOD remaining is the expected result for a 6-ft filter operated as a single pass unit at this hydraulic load. According to these data a limiting organic load for trickling filters has not been established so far and a constant percentage of BOD removal at a given hydraulic load and depth may be expected at organic loads up to 25 lb BOD/day/cu yd or more. Whether this can be done in practice without clogging the filter is another problem.

Temperature Effect

Besides depth and hydraulic load there is a third major factor affecting the efficiency of trickling filters—temperature. According to Table V the average sewage temperature for most of the runs varied between 20.2 and

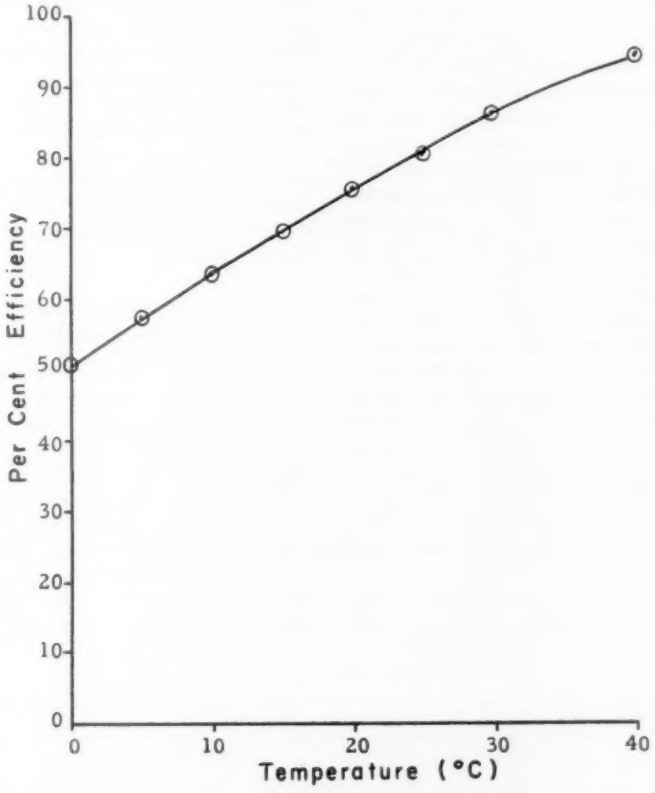

FIGURE 8.—Theoretical curve for temperature effect on a 6-ft filter with a loading of 5 mgd/acre and K_{20} of 0.3.

22.1°C. There were only two runs with average temperatures from 14.1 to 15.8°C. The value for $K = 0.30$ derived from these experiments is therefore assumed to be close to K_{20}, the value for K at 20°C. Based on data published by Schroepfer *et al.* (9), Howland (3) introduced a temperature correction factor of 1.035^{T-20} for K_{20}. The complete equation relating BOD removal to depth, hydraulic load, and temperature would then be:

$$\frac{L_e}{L_i} = 10^{-bK_{20}D/Q^{\frac{1}{2}}} \quad \ldots\ldots (10)$$

where

$b = 1.035^{T-20}$,
T = temperature in centigrade degrees, and
$K_{20} = 0.3$.

Using this formula the effect of temperature on the efficiency of trickling filters at a given depth and hydraulic load can be computed. As an example, the efficiency of a single pass filter of a depth of 6 ft at a hydraulic load of 5 mgd/acre has been computed for a range from 0 to 40°C. The resulting curve is shown in Figure 8. There were no experimental data available for comparison with the theoretical curve. Judging from general experience, the temperature effect appears to be somewhat exaggerated, since an increase in temperature from 10 to 20°C would increase the efficiency by about 12 per cent. On the other hand, at 0°C, an efficiency of 50 per cent is still obtained, and it appears that the temperature correction factor may need modification.

The experiments on the screen trickling filter were conducted in a room held at about 70°F. During one run at an average hydraulic load of 5 mgd/acre when the heater failed, two sets of data were obtained, one at an average sewage temperature of 9.8°C and the other at an average sewage temperature of 19.6°C. The average efficiencies for these two runs were compared by the *t*-Test and the results are shown in Table VI.

The data show that for a 9.8°C increase in temperature the efficiency increased by 5 per cent and that this difference was statistically significant. The increase in efficiency is smaller than the one predicted by Equation 9, which is 12.3 per cent for a temperature increase from 10 to 20°C. The experimental data available are not sufficient to evaluate the temperature effect and more study is needed in this neglected area of research. Nevertheless Equation 10 provides a basis for computing the efficiency of trickling filters for any given combination of hydraulic load, depth, and temperature, as long as the organic load does not reach a critical limit. As mentioned before, trickling filters generally operate far below this limit.

Application to Data From Other Investigators

To find out whether the data obtained from the screen trickling filter were compatible with those obtained from experiments with conventional filter media, the results of British trickling filter experiments at Minworth, England (10), were used. The filter beds were 6 ft deep, made from crushed stone or gravel and had a surface area of 36 sq ft. They were operated as single pass units with settled

TABLE VI.—Effect of Temperature

Groups	Avg Temp. (°C)	Avg Q (mgd/acre)	Avg Efficiency (per cent)	No. Data	Degrees of Freedom	t	Crit. Value for t at 1 Per Cent Prob. Level
A	9.8	4.97	71.0	13	21	4.17	2.83
B	19.6	5.0	76.0	10	—	—	—

TABLE VII.—Relationship Between Hydraulic Load and Efficiency (from Reference 10)

Q (mgd/acre)	t	K	Theor. BOD Remaining (per cent)	Exper. Avg BOD Remaining (per cent)
2.3	3.41	0.26	9.5	13
5.2	1.98	0.28	25.4	28
7.0	1.64	0.31	32.3	31
9.3	1.35	0.33	39.4	36
11.6	1.16	0.27	44.8	49
14.5	1.00	0.32	50.1	48
17.4	0.88	0.30	54.2	54
23.2	0.73	0.33	60.3	57

sewage at hydraulic loads varying from 2.3 to 23.2 mgd/acre. The results from three months' operation and their application to the formulations used here are shown in Table VII and Figures 9 and 10.

As a first step, log per cent BOD remaining was plotted against log Q in mgd/acre as shown in Figure 9. The experimental data fit a straight line reasonably well and the equation for this line was

$$\frac{L_e}{L_i} = aQ^c = 0.088Q^{0.64} \ldots . (11)$$

which is in close agreement with Equation 1a.

The per cent BOD remaining of these filters was directly related to hydraulic load Q to the 0.64th power. This factor is also close to the 2/3rd power as used in Equation 5 and the whole plot is very similar to the one shown in Figure 4 for the screen trickling filter data.

Next, per cent BOD remaining was plotted against the time factor t on semilog paper and the data were compared with those from the screen filter by plotting Equation 8 the same way as in Figure 5, using $K = 0.3$. Figure 10 shows that the experimental results from the filters at Minworth using conventional media agree very well with those from the screen filter. The experimental K values varied between 0.26 and 0.33 as shown in Table VII. The agreement in regard to the K-values is surprising. The expectation was that for identical hydraulic loads the actual contact time and therefore the efficiency with conventional filter media would be greater than with the screen filter. This should result

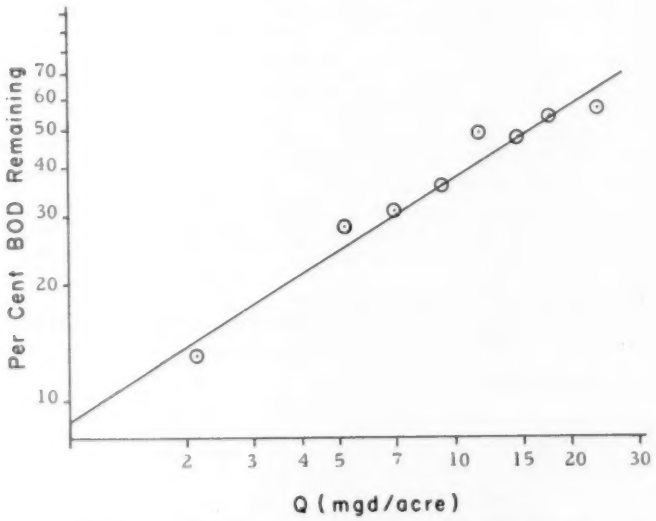

FIGURE 9.—Filter performance (Data from Reference 10).

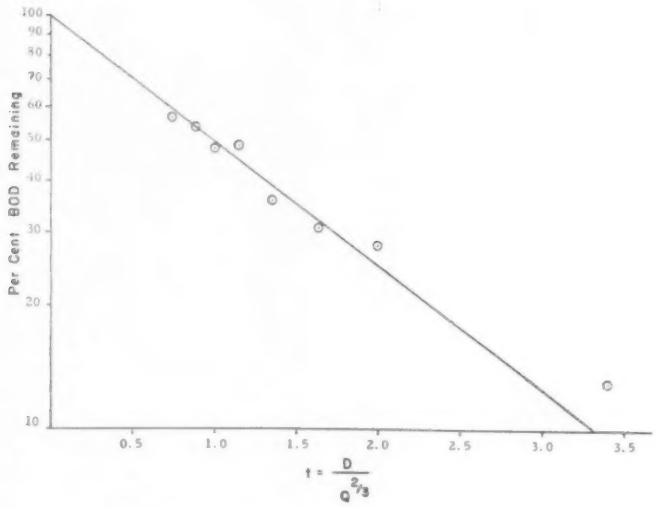

FIGURE 10.—Effect of time on filter performance.

in higher K-values. It is possible that the conformity in K-values was purely coincidental since the true contact time would depend not only on the filter media but also on the method of distribution used. For most distributors the instantaneous coverage is only a fraction of the total filter surface and the actual hydraulic load is therefore much higher than the one used for the computations.

Comparison of the data shows, however, that there is no basic difference between the screen trickling filter and conventional filters. The same laws apply to both. The performance of a single pass trickling filter can therefore be predicted for any given combination of depth, hydraulic load, and temperature; or the size of a single pass filter can be computed for a given efficiency, hydraulic load, and temperature.

Recirculation

The type of equation developed here should also be applicable to the problem of recirculation. According to Equation 4, the fraction of BOD remaining in final effluent for a single pass filter is given by:

$$p_1 = \frac{L_e}{L_i} = 10^{-KD/Q_1^{\frac{1}{2}}} \quad \ldots\ldots (12)$$

where Q_1 = hydraulic load to filter in mgd/acre with recirculation.

If recirculation is used, the hydraulic load to the filter is determined by the recirculation ratio r, so that the new hydraulic load is:

$$Q_2 = Q_1(1 + r) \quad \ldots\ldots (12a)$$

where

Q_2 = hydraulic load under recirculation, and
$r = R/I$ = ratio of recirculation flow to incoming waste flow.

The fraction of BOD remaining under these conditions is:

$$p_2 = \frac{L_{er}}{L_m} = 10^{-KD/Q_2^{\frac{1}{2}}} \quad \ldots\ldots (13)$$

and

$$L_m = \frac{L_{er}}{p_2} \quad \ldots\ldots (14)$$

where

L_{er} = BOD concentration of final effluent or recycle flow in mg/l,
L_m = BOD concentration of mixed flow (incoming and recycle) in mg/l, and
Q_2 = hydraulic load in mgd/acre including recirculation flow.

In this formulation, final effluent is used for recirculation and is mixed with incoming waste directly ahead of the filter. The filter is considered to operate basically the same way as a single pass filter, except that the hydraulic load is increased according to r and that the degree of BOD removal is now related to the BOD of the mixed flow. The BOD concentration of the mixed flow is given by:

$$L_m = \frac{rL_{er} + L_i}{1 + r} \quad \ldots\ldots (15)$$

Combining Equations 14 and 15:

$$\frac{L_{er}}{p_2} = \frac{rL_{er} + L_i}{1 + r} \quad \ldots\ldots (16)$$

and rearranging:

$$L_{er} = \frac{L_i}{\left(\frac{1 + r}{p_2}\right) - r} \quad \ldots\ldots (17)$$

The fraction of BOD remaining in final effluent in relation to the actually incoming (untreated) BOD is then given by:

$$p_3 = \frac{L_{er}}{L_i} = \frac{1}{\left(\frac{1 + r}{p_2}\right) - r} \quad \ldots (18)$$

A comparison of p_1 and p_2 under otherwise identical conditions should then show the effect of recirculation on the efficiency.

An application of these equations for a six-foot trickling filter operated at an incoming flow of 5 mgd/acre, single pass and with 1:1, 1:2, and 1:3 recirculation is given in Table VIII. The strength of the incoming waste has been assumed to be 100 mg/l BOD.

According to these theoretical data recirculation does not improve the quality of the final effluent under the conditions discussed here. What is gained by dilution of the incoming BOD is lost by the decrease in p_2 due to the increased hydraulic load. Similar conclusions were reached by Howland (3) in his more comprehensive mathematical treatment of this problem. In practice, there is general agreement that recirculation increases the efficiency as shown by the empirical NRC formula. Whether this difference is due to secondary factors, such as more equalized hydraulic loads, better distribution over the filter, and less clogging under recirculation, or to flaws in the theory remains open for decision by the experiment.

Discussion

General practice has been to plot efficiency against organic load, as shown by the NRC formula:

$$E = \frac{100}{1 + 0.0085 \sqrt{\frac{W}{VF}}}$$

TABLE VIII.—Effect of Recirculation for Filter Depth of 6 ft and K of 0.3

Incoming or Outgoing Flow (mgd/acre)	Recirc. Ratio r	Q_1 or Q_2 (mgd/acre)	L_i (mg/l)	L_m (mg/l)	p_2	p_3	p_1	Efficiency (per cent)
5	0	5	100	—	—	—	0.244	75.6
5	1	10	100	63.0	0.412	0.259	—	74.1
5	2	15	100	50.5	0.509	0.257	—	74.3
5	3	20	100	43.7	0.573	0.251	—	74.9

where

E = per cent efficiency,
W = applied load in pounds BOD per day of settled raw sewage,
F = recirculation factor $= \dfrac{r+1}{(0.1r+1)^2}$,
r = recirculation ratio, and
V = volume of filter media in acre feet.

For single pass filters, $F = 1$, the only variable introduced into the formula is $\dfrac{W}{V}$, which is organic load expressed as pounds BOD per day per acre foot. The efficiency is thus assumed to vary according to organic load alone. Hydraulic load is not considered as a factor, or only indirectly. The experimental data presented here show that within certain limits the hydraulic load is the factor governing efficiency, rather than the organic load. The apparent agreement between actual filter efficiencies and those predicted by the NRC formula may be explained by the fact that this formula was developed for municipal wastes with a fairly narrow range of BOD values, say from 100 to 200 mg/l. In this case, increase in organic load is nearly analogous to increase in hydraulic load. The NRC formula would certainly fail, however, where industrial wastes are concerned. Here, a high organic load can be produced at relatively low hydraulic loads and, therefore, the NRC formula would result in efficiencies which are too low compared to those predicted by the new formula. For example, the efficiency of a single pass filter, 6 ft deep, treating primary effluent of an average BOD of 150 mg/l at a hydraulic load of 5 mgd/acre would be 81.6 per cent according to the NRC formula and 75 per cent according to the new formula. If under the same conditions a waste having a BOD concentration of 600 mg/l were treated, the NRC formula would predict an efficiency of 69 per cent, whereas, according to the new formula the efficiency would remain unchanged at 75 per cent.

The fact that at any given hydraulic load a constant percentage of the applied organic load is removed, makes the trickling filter process very similar to an adsorption process. Experimental data by Katz and Rohlich (11) showed that at a given concentration of activated sludge the amount of BOD removed was a constant fraction of the applied BOD. The process could be expressed by the following modified Freundlich adsorption isotherm:

$$\frac{C_a}{C_s} = K'C_e^n \quad \ldots\ldots\ldots (19)$$

where

C_a = original concentration of adsorbate (original BOD, mg/l),
C_s = concentration of adsorbent (activated sludge, mg/l),
C_e = equilibrium concentration of adsorbate (residual BOD, mg/l),
K' = constant, and
n = constant = 1.

If the concentration of adsorbent, such as the active biological film in a trickling filter, is assumed to be constant, and since n was found to be unity, the equation simply becomes:

$$C_a = K'C_e \quad \ldots\ldots\ldots (20)$$

In other words the BOD remaining after treatment is a constant fraction of the applied BOD.

This is the same result as that shown by a trickling filter under constant hydraulic load and it is also the basis for the equations developed previously in this paper. Applied to trickling filter formulations Equation 20 can be written:

$$L_i = K'L_e \quad \ldots\ldots\ldots (20a)$$

so that

$$K' = \frac{L_i}{L_e} = \frac{1}{p} \quad \ldots\ldots\ldots (20b)$$

K' is, therefore, equal to the inverse of the fraction of BOD remaining in

the effluent. It is interesting to note that according to Equations 4 or 5, K' remains constant only for a given hydraulic load. Katz and Rohlich (11) found in their activated sludge experiments that equilibrium concentration was reached after a contact time of approximately 20 min, a contact time which has been generally postulated for trickling filters. As mentioned before, according to Howland (3) contact time varies inversely with the two-thirds power of the hydraulic load. Data presented here have shown that the fraction of BOD remaining is proportional to the two-thirds power of the hydraulic load. The trickling filter process therefore appears as an adsorption process where hydraulic load determines contact time and this in turn determines the level of efficiency at which the process operates.

Summary

Experimental data have shown that:

1. At constant hydraulic loads the efficiency of a trickling filter remains constant for organic loads up to 11 lb of BOD per day per cubic yard.
2. The fraction of BOD remaining is proportional to the two-thirds power of the hydraulic load.
3. An equation is presented relating filter efficiency to depth, hydraulic load, and temperature, using an experimentally determined constant $K = 0.3$.
4. The application of this equation to determine the effects of recirculation is discussed.
5. The conformity between the adsorption process and the trickling filter process is pointed out.

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NEW SEWER DESIGN MANUAL ANNOUNCEMENT ON PAGE 129a.

ORDERS ARE BEING ACCEPTED FOR NEW SEWER MAINTENANCE MANUAL—SEE PAGE 137a. ORDERS FILLED AS SOON AS BOOKS RECEIVED FROM PRINTER

Industrial Wastes

CONTROL OF RADIOACTIVE POLLUTION OF THE ANIMAS RIVER*

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Under the enforcement provisions of the Federal Water Pollution Control Act of 1956, a comprehensive study of pollution of the interstate waters of the Animas River has been completed recently. The Animas flows south from Colorado into New Mexico, receiving wastes from mining operations near its source, domestic sewage, and wastes from a uranium ore refinery in Colorado. The principal source of interstate pollution was found to be the uranium ore refinery, which discharged both chemical and radioactive wastes to the river. The general objectives of the required studies included measurement of the extent of pollution, its effects on existing downstream water uses, and estimates of the total internal radiation exposure of downstream populations. These studies are offered as one practical approach to the problem of rational control of radioactive water pollutants. They illustrate some of the techniques and problems of planning such a survey, interpreting its results, and instituting remedial measures.

Background

Tsivoglou *et al.* have reviewed general problems of uranium ore refining wastes (1). In a typical uranium ore refinery, or mill, uranium is extracted from the raw ore from local mines, and concentrated. The concentrate then goes to other plants for further refining and processing, fabrication into reactor fuel elements and other devices, and eventual use in nuclear reactors. At present, 23 operating uranium mills in the western states process some 21,000 tons per day of ore containing about 0.28 per cent U_3O_8. The refinery on the Animas River was processing slightly more more than 500 tons of ore daily at the time of these studies.

Uranium is the parent, or first member, of a long series of radioactive isotopes found in nature. It decays by successive alpha and beta emissions through 14 daughter elements to a nonradioactive isotope of lead. All of the daughter elements, including thorium, polonium, radium, bismuth, and others, are found naturally along with the uranium. However, only the uranium is wanted, and all of the remaining radioactive daughter elements are rejected as process wastes at the refineries. These process wastes include wash waters and certain process liquors, as well as the sands and waste ore solids that have been stripped of their uranium. Typically, these wastes are discharged to "tailings ponds," or

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lagoons, where the solids settle, and where the liquids are reduced in volume by evaporation and seepage. Excess liquids are often discharged directly, without further treatment, to a nearby stream, which may also receive seepage from the tailings pond.

Radium is the most hazardous radioelement contained in uranium mill wastes. Its maximum permissible concentration in drinking water is exceedingly small, and its ingestion in water or in contaminated food or milk is regarded as quite dangerous. Hence, uranium mill waste discharges to a stream may seriously interfere with such water uses as domestic supply, crop irrigation, and stock watering. In addition, the discharge of toxic chemicals can inhibit or destroy aquatic life, thereby depriving downstream populations of the recreational use of the stream. As will be seen, waste discharges from the Durango, Colorado, uranium mill contained sufficient radium and toxic chemicals to interfere seriously with the downstream use of the Animas River.

Locale of Survey and Water Uses

Figure 1 is a detailed map indicating the general locale and extent of the environmental surveys. The Animas rises in rugged mountains in the vicinity of Silverton, Colorado. It proceeds south from there some 50 miles to Durango, Colorado, and joins the San Juan River about 60 river miles south and west of Durango, at Farmington, New Mexico. North of Durango the terrain is mountainous and the river valley quite narrow,

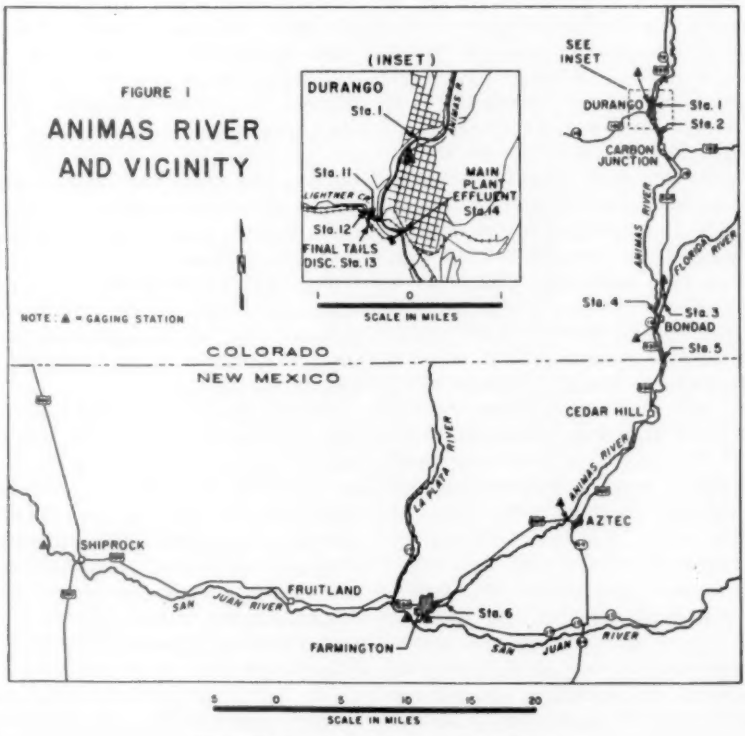

FIGURE 1.—Animas River and vicinity.

while to the south the country is less rugged and becomes more suitable for farming. Precipitation is markedly reduced in the New Mexico reaches, and the San Juan Basin below Farmington is relatively arid. The primary survey area included some 60 miles of the Animas River, from a location above Durango to the confluence with the San Juan. In addition, limited sampling was undertaken near Shiprock, New Mexico, on the San Juan.

The Animas near Durango and downstream is used for a variety of purposes. It serves as a source of domestic water supply for Aztec and Farmington, New Mexico, with populations of approximately 6,000 and 22,000 people, respectively. Durango obtains the water supply for its 11,500 people from the upper Florida River, which is the only major tributary of the Animas, and which lies wholly in Colorado. In addition to these treated community supplies, Animas River water is used in its raw state south of Durango by approximately 100 people in Colorado and by an estimated 1,845 people in New Mexico (2), who take water directly from the Animas or from irrigation ditches carrying Animas River water. Below Farmington, an estimated 2,310 persons use the San Juan River as a source of raw water supply (3), and Shiprock obtains its municipal supply from the San Juan.

Below Durango the Animas provides water for irrigation ditches which serve some 26,000 acres of croplands above Farmington. An additional 36,000 acres between Farmington and Shiprock are irrigated with waters of the San Juan. A wide variety of crops, including root and leaf vegetables, cereals and grains, and fruits is grown in the area.

The river near Durango also serves as a recreational area, and is used to some extent for swimming and fishing. Fishing in and immediately above Durango is prevalent. Downstream from Durango the Animas is used for stock watering, both directly and via the irrigation ditches. It also serves as a source of industrial process water supply for the uranium mill, and carries away the waste discharges from this ore refinery as well as from the City of Durango and sundry other small sources. Thus, the Animas is a vital natural resource of the area.

Prior Data

The uranium refinery at Durango has been in continuous operation since 1948. In 1950, at the request of the interested states, samples of water were collected from river locations above and below the mill. Dissolved radium amounted to 0.2 and 4.5 $\mu\mu$c/l, respectively. The flow in the river was 220 cfs at the time of sampling.

In 1955 a second brief survey was performed at Durango (4). Samples of water, mud, algae, and aquatic insects were collected from the river above and below the mill, as well as effluents. At the river flow of 250 cfs, dissolved radium was again 0.2 $\mu\mu$c/l above the mill and 3.3 $\mu\mu$c/l below. The algae and aquatic insects above the mill contained 6 $\mu\mu$c of radium per g of ash, while below they contained 660 and 360 $\mu\mu$c/g, respectively. The two effluents from the mill contained 76 and 25 $\mu\mu$c/l of dissolved radium. The gross alpha activity of suspended solids in the main effluent was 33,200 $\mu\mu$c/l.

Thus, both the 1950 and 1955 samples indicated a gain in the dissolved radium content of the river by a factor of about 20, and an approximate gain of 2.0 mg/day of dissolved radium. The aquatic biota samples of 1955 indicated some concentration of radium by algae and insects, the downstream samples having from 60 to 110 times the radium content of those from above the mill.

The foregoing data represent only isolated samples that cannot be considered as representative of any long

period of time. Also, at the time of these analyses, the accepted standards for radiological safety (5) did not indicate that the pollution problem was serious. It was not until 1957 that the possible serious nature of the problem became evident. At that time, the MPC's of Handbook 52 were revised downward by a factor of 10 for general population exposure (6), and the regulations of the U. S. Atomic Energy Commission for waste discharges by its licensees were published (7). Both of these publications indicated that the pollution problem downstream from Durango was more serious than had been suspected, and warranted careful attention.

Shortly thereafter the New Mexico Department of Public Health requested that the Public Health Service investigate this case of pollution of interstate waters and arrange for any necessary remedial measures. As a result of this request, a conference as prescribed by Public Law 660 was held in April of 1958, at Santa Fe, New Mexico, at which were represented the States of Colorado and New Mexico, the Public Health Service, the uranium company, and all other interested agencies and individuals. It was the conclusion of that group that the existing data were not sufficient as a basis for determining the extent of interference with water uses in New Mexico, or necessary remedial measures. Accordingly, the conferees directed the Public Health Service to carry out a one-year fact-finding survey having the following objectives:

1. Evaluate the internal radiation exposure to radium and strontium-90 in the Durango-Farmington population area, and the portion of this total exposure that resulted from radium and other waste discharges from the uranium refinery at Durango, Colorado.

2. On the basis of the above evaluation and other tests, assess the interstate pollutional aspects of the uranium refinery waste discharges.

Radiation Exposure and Existing Standards

Before describing in detail the fact-finding survey and its results, it is pertinent here to outline the basic principles and existing standards for radiological protection.

Maximum Permissible Concentrations (MPC's) in air and in domestic water supply for most radioelements are listed in Handbook 52, National Bureau of Standards (5), and these are the basic recommendations of the National Committee on Radiation Protection for protection against excessive internal radiation exposure. An addendum (6) to Handbook 59, National Bureau of Standards, indicates that the concentrations listed in Handbook 52 represent allowable internal exposure for radiation workers, and should have a safety factor of 10 applied for protection of the general population outside the controlled area, or industrial site. These MPC's refer to the amount of any listed radioisotope that can be ingested in domestic water supply continuously over a lifetime without producing any readily detectable biological damage. The newly released Handbook 69 (8) revises the MPC's listed in Handbook 52 for the exposure of radiation workers, and also includes suggested maximum allowable levels of exposure for "persons in the neighborhood of controlled areas." It does not, however, provide figures for the protection of the general public, and hence reliance must still be placed on Handbook 52 with its addendum, or on the recommendations of the International Commission on Radiological Protection (9) for this purpose.

Radium is a long-lived alpha emitter that deposits in the bones. It decays successively to several other elements, or daughters, that are also radioactive.

The MPC for radium plus one-half of the equilibrium amounts of its radioactive daughters in a public water supply is 4 $\mu\mu$c/l (5)(6). This is the lowest of all of the MPC's, and in these terms radium is considered the most hazardous of all the listed radioisotopes.

Strontium-90 also decays to a radioactive daughter, yttrium-90, and the MPC for strontium-90 plus an equilibrium amount of yttrium-90 in domestic water supply is 80 $\mu\mu$c/l (5)(6). Strontium is also relatively long-lived, emits beta particles during decay, and deposits primarily in the bones. It has next to the lowest of all of the Handbook 52 MPC's in domestic water supply, being second only to radium in this regard. Its source in the environment is the fallout from nuclear weapons tests.

The basic principle of protection against internal radiation exposure is to place an upper limit on the amount of exposure that can be allowed for the affected organ. This has the effect of placing an upper limit on the total allowable intake of any particular radioisotope. Thus, if radium were the only radioisotope involved here, and if the domestic water supply were the only means of human intake, then the domestic water supply could allowably contain as much radium as is specified by its MPC. If, however, radium is ingested via several paths such as domestic water supply and crops that have radium in them, then the total intake of radium must be considered. Hence, if the crops contained a relatively large quantity of radium, the content of the water supply would have to be severely limited, at some level well below the MPC. Conversely, if the domestic water supply were to contain the maximum permissible amount of radium, then intake via other paths such as food would result in exceeding the safe radiation exposure.

The same principles apply to combinations of radioisotopes that affect the same organ. Thus, because radium and strontium both affect the bones, they must be considered together as a source of internal radiation exposure, and the allowable intake of one is directly affected by the presence of the other. For example, if a domestic water supply were to contain the maximum permissible amount of strontium-90 then no radium could be permitted in it, and vice versa; or, if the water supply contained half of the MPC of strontium-90, then only half of the radium MPC could be allowed. The intake of either of these radioelements by other paths such as food or milk would further restrict the allowable intake via the domestic water supply.

In determining criteria for the safe disposal of radioactive wastes it is important to consider all means by which the local population group is exposed to radiation. The effects of radiation exposure are cumulative, and the total exposure of a population is much more significant than the fraction of it associated with one particular source such as drinking water. An individual or a community may drink slightly contaminated water and milk, eat slightly contaminated food, and breathe slightly contaminated air. A portion of the individuals may during their working hours inhale or ingest somewhat higher amounts of radioactive materials as a result of their occupation in the nuclear industry. It is the total exposure that has real significance, and it is important to examine each source, such as a domestic water supply, in the light of the total radioactivity intake from all local sources. While any individual exposure, such as that from the domestic water supply, may be lower than the maximum allowable, the total radiation exposure from all sources may exceed that regarded as safe.

Finally, in regard to the numerical MPC's, the following cautionary statement is included in Handbook 52, and

its sense is also contained in the more recently released Handbook 69:

> "Because of the many uncertainties involved, this Committee recommends that every effort be made to keep the concentrations of radioisotopes in air and water and in the body to a minimum. The goal should be *no* radioactive contamination of air and water and of the body if it can be accomplished with reasonable effort and expense. If such a goal cannot be attained, the average operating levels should be kept as far below these recommended values as possible, and not above them for any extended periods of time."

The Mill Process

With the cooperation of the company, an in-plant survey of the Durango ore refinery was performed in early August 1958. Both vanadium and uranium are extracted from the ores received. At the time of the survey the mill was handling 514 tons/day of ore, and planned to increase capacity to 700 or 750 tons/day. Details of the extraction process are presented elsewhere (10) but a brief description is presented below.

The ore is weighed, crushed and ground, and sampled on receipt at the mill. Salt is then added and the mixture is roasted to convert vanadium to a soluble form. It is then leached with Na_2CO_3; uranium is precipitated from this alkaline leach liquor with sulfuric acid, and the resulting yellowcake is washed, dried, and barreled for shipment; the filtrate from uranium precipitation is then heated, more sulfuric acid is added, and vanadium is precipitated as redcake, which is washed and fused and barreled. The leached sands from the Na_2CO_3 leach go to a separate circuit for extraction of uranium and additional vanadium by the acid leach solvent extraction process; they are leached with H_2SO_4, and the leached sands are then discharged to the final tailings pond; the acid leach liquor has its pH adjusted by use of Na_2CO_3 and goes to the solvent extraction circuit; here uranium and vanadium are stripped from the leach liquor by the organic solvent (tributylphosphate, kerosene, heptadecanol, and a trifatty amine are used). The stripped leach liquor, or organic raffinate, is discharged as waste, while uranium and vanadium are stripped from the loaded organic by Na_2CO_3 solution; the loaded Na_2CO_3 solution then goes to the alkaline leach tanks mentioned earlier for precipitation of uranium as yellowcake and vanadium as redcake.

At the time of the survey a small fraction of the acid leach liquor went to an acid purification plant for removal of impurities. The resulting iron-aluminum sludge went to waste. This circuit has been eliminated since that time.

Some of the chemicals used in the extraction process included 65,000 lb/day of sulfuric acid, 48,000 lb/day of salt, and about 64,000 lb/day of soda ash. Tributylphosphate used amounted to about 325 lb/day, and kerosene to about 370 gpd.

The two effluents from the mill included all of the waste liquors and some solids. The main effluent to the Animas contained the vanadium filter tray wash waters, the organic raffinate, and the liquid from the sands following the initial alkaline leach, as well as the iron-aluminum sludge. Effluents from the final tailings pond discharged primarily to Lightner Creek.

During the week-long in-plant survey the main effluent to the Animas River averaged 270 gpm, and had a dissolved solids content of 35,400 mg/l and a suspended solids concentration of 5,600 mg/l. The effluent from the tailings pond to Lightner Creek averaged about 70 gpm; its dissolved and suspended solids concentrations were 13,000 and 11,000 mg/l, respectively.

The Field Survey

Sampling

In order to provide the information required to proceed with pollution

abatement in the Animas River, an extensive field survey was begun in July 1958. Figure 1 shows the location of river sampling stations. Station 1, located one mile above the uranium mill, served as a background or control location. Station 2 was about two river miles below the mill, at a point where the mill effluents were thoroughly mixed with the river. Station 3, near the mouth of the Florida River, provided data as to the quality and amount of tributary flow, while Station 4, about 23 miles below the mill, indicated Animas River quality just above the confluence with the Florida. Station 5 was located at the Colorado-New Mexico line, about 28 miles below the mill, and Station 6, at Farmington, New Mexico, was approximately 59 river miles below the mill and 3 miles above the junction of the Animas with the San Juan.

In addition to these, Station 7 was located at the Aztec, New Mexico, water plant, Station 8 at the Farmington, New Mexico, water plant, and Station 9 at the Shiprock, New Mexico, water plant. Station 10 was located about 100 yd downstream from the main effluent from the mill, and Stations 11 and 12 on Lightner Creek were just below and above the effluent to this tributary. The main effluent from the mill was sampled at Station 14 and the effluent to Lightner Creek at Station 13.

For a two-month period beginning in July 1958, sampling was continuous. Automatic water samplers were installed at Stations 2 and 5, and for the 8 survey weeks these devices collected small amounts of water every 15 min. The sampler is described elsewhere (10). The collection jug was emptied daily, and weekly composites were analyzed for various constituents. At Stations 1, 3, 4, and 6 daily grab samples collected across the stream at quarter points were composited on a weekly basis for analysis. These six stations were also sampled every two weeks for mud, algae, and aquatic insects.

Sampling of raw and treated water was on a regular basis at the three water plants. Weekly composites for analysis were made up of pint samples taken every six hours. Samples of filter sand were taken occasionally, both before and after backwashing.

Stations 10 and 14 were sampled daily, and Stations 11, 12, and 13 were sampled daily when the effluent to Lightner Creek was flowing.

Fish samples were collected once during the summer of 1958 in the vicinity of Stations 1, 2, and 5. DO, BOD, and coliform samples were collected at two-week intervals during the summer at locations above Durango, below Durango, near the Colorado-New Mexico line, below Aztec, New Mexico, and below Farmington, New Mexico.

Samples of each rainfall that occurred during the two-month survey period were taken at Durango and Farmington, for analysis for fission products and strontium 90. Samples of locally produced milk were obtained on a monthly basis, also for strontium-90 and other analyses.

In addition to the above, samples of vegetable and fruit crops, topsoil, and irrigation water were collected periodically from a group of three farms located above Durango, and from a second group of six farms located below the uranium mill. All of the farms involved used the Animas as the source of irrigation water. The food samples collected were cleaned carefully in the field laboratory at Farmington in a manner calculated to approximate usual household food preparation. They were then preserved for later analysis.

All samples were delivered initially to a field laboratory, made available at Farmington, New Mexico, by the San Juan County Health Department. There most samples were prepared for subsequent analysis at the Cincinnati

or Salt Lake City Laboratories of the Public Health Service. Others such as DO, BOD, and coliform samples were analyzed at once in the field. Gross radio-assay of selected samples of all types was performed at the field laboratory in order to provide immediate information as to the progress of the survey and the relative importance of types of samples. Details of sample preparation and analytical methods are given in the report of the survey (10).

Following the intensive summer survey, certain of the sample collections were continued on a routine monthly basis by personnel of the local and State health units. These were shipped to the Robert A. Taft Sanitary Engineering Center for analysis. They included milk, samples from the water plants, and river samples from Stations 1, 2, and 5.

Also during the late summer of 1958 bio-assay studies of the mill effluents and specific waste liquors were performed, and a census of aquatic insect populations was made at the river sampling stations.

Hydrology

Stream flow records for the Animas River at several gaging stations have been maintained at least intermittently since 1895, and the data are available in publications of the U. S. Geological Survey (11). Continuous records are available for the period October 1, 1934, through September 30, 1956, for stream gaging stations at Durango, Cedar Hill, and Farmington on the Animas River and at Farmington and

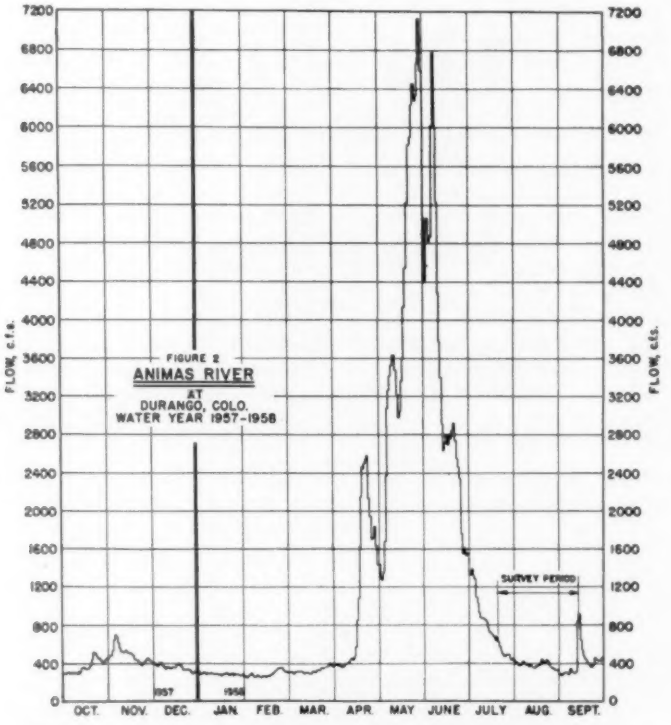

FIGURE 2.—River flow pattern at Durango, Colorado, for water year 1957–58.

TABLE I.—Low Flow Frequencies, Durango

Return Period	Minimum Average Flow (cfs)		
	7 day	14 day	30 day
1 in 2 yr	161	165	171
1 in 5 yr	142	148	155
1 in 10 yr	130	137	144
1 in 20 yr	118	126	135

Shiprock on the San Juan. These data were supplemented by copies of the stage-recorder charts for the water year October 1, 1957, through September 30, 1958, which included the period of the 1958 summer field survey. As an illustration of the river flow pattern at Durango, a typical daily hydrograph for that location is shown by Figure 2.

Flow records for the Animas River at Aztec, New Mexico, were also obtained on a temporary basis by the U. S. Geological Survey, which established a wire-weight gage at Aztec specifically for these studies.

The continuous flow records for the period 1934–56 at Durango, Cedar Hill, and Farmington on the Animas and at Farmington and Shiprock on the San Juan, have been analyzed for low flow frequencies by the use of probability techniques (12). The detailed results of these analyses are available in the comprehensive survey report (10). The primary dilution of mill effluents occurs at Durango, and Table I indicates results of the analysis for that location, for 7-, 14-, and 30-consecutive day periods. For example, a minimum 30-day average flow as low as 155 cfs may be expected at Durango once every five years. The minimum daily flow of record at Durango was 110 cfs.

The effects of local irrigation practice are of interest, and are illustrated in Figure 3, which shows the distribution of minimum daily and monthly average flows by month of occurrence. Upstream regulation of flows has negligible effect at Durango, and the minimum flows occur primarily during the freezing winter months. On the other hand, much of the flow of the Animas is diverted above Farmington to serve some 26,000 acres of farmland; as a result, the minimum flows at Farmington occur primarily during the late summer, and the recent record shows a minimum daily average flow at Farmington of only 2.4 cfs.

Table II shows the average flows by weeks at each of the primary river sampling points for the two-month 1958 survey period. These flows were estimated on the basis of records at the several gaging stations, and correspond to the weekly compositing schedule for water samples.

Rainfall at Durango for the two-month summer survey period totaled 3.42 in., and at Farmington 2.70 in. Total annual precipitation for calendar 1958 was 16.01 in. at Durango and 8.44 in. at Farmington. This was close to the average year of record at these locations. The figures reflect the dif-

TABLE II.—Mean Flow at River Sampling Stations During Survey Period, by Weeks

Sample Sta. No.	Sample Week Mean Flow (cfs)							
	1	2	3	4	5	6	7	8
1	500	415	385	460	405	335	290	295
2	505	420	390	365	410	340	295	300
3	17	17	19	25	~30	~25	~20	~20
4	590	495	430	395	450	350	275	300
5	605	510	450	420	480	375	295	320
Aztec	410	380	310	290	370	310	225	210
6	310	270	180	165	330	240	140	130

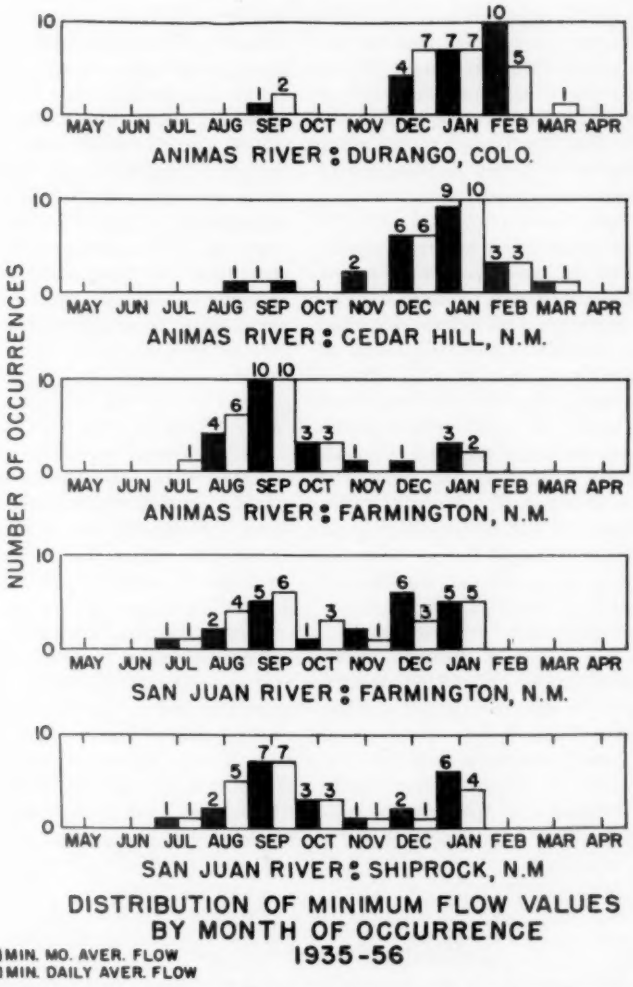
NUMBER OF OCCURRENCES
ANIMAS RIVER : DURANGO, COLO.
ANIMAS RIVER : CEDAR HILL, N.M.
ANIMAS RIVER : FARMINGTON, N.M.
SAN JUAN RIVER : FARMINGTON, N.M.
SAN JUAN RIVER : SHIPROCK, N.M
MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR
DISTRIBUTION OF MINIMUM FLOW VALUES
BY MONTH OF OCCURRENCE
1935-56
MIN. MO. AVER. FLOW
MIN. DAILY AVER. FLOW

FIGURE 3.—Flow distribution for the Animas and San Juan Rivers in the Durango vicinity.

ference in terrain, the Durango area being mountainous and rather rugged, while the Farmington area is flatter and more open.

Survey Results

The detailed results of analysis of all samples collected during the survey are presented elsewhere (10). A summary of the more pertinent data is given below.

Mill Samples

During the week-long in-plant survey an average of 11,000 lb/day of vanadium as V_2O_5 and 3,250 lb/day of uranium as U_3O_8 was produced at the mill. Based on radio-assay of samples taken within the mill and measurements of effluent flows and solids concentrations, it was estimated the raw ore contained 2.3 curies/day

of gross alpha radioactivity. Of this, 1.7 curies/day were retained in the tailings pond with sand and slimes solids, 0.4 curie/day was included in the uranium concentrate, and 0.2 curie/day was discharged to the river in the effluents. About 15 tons/day of undissolved sands and slimes were released to the river.

Analysis of selected effluent samples for dissolved uranium and radium yielded concentrations of from 3 to 57 mg/l of uranium and from 44 to 822 $\mu\mu$c/l of radium. On the basis of these figures and the observed effluent flows it was estimated that as much as 160 lb/day of dissolved uranium was wasted to the river, and a maximum of 0.8 mg/day of dissolved radium was released. In the undissolved state an estimated 30 mg of radium were released daily. As will be seen, this figure has real significance in terms of river water quality.

According to data presented earlier, about 46,000 lb/day of sodium, 29,000 lb/day of chloride, and 68,000 lb/day of sulfate were used in the mill process. These figures are based on chemical consumption data supplied by the company records. Analysis of representative mill effluent samples for these constituents, together with observed flows, indicated that 34,400 lb/day of sodium, 20,000 lb/day of chloride, and 65,500 lb/day of sulfate left the mill as dissolved solids in the effluents. Analysis of river water samples for Stations 1 and 2, together with river flows, indicated that 47,000 lb/day of sodium, 25,000 lb/day of chloride, and 76,000 lb/day of sulfate were added to the river by the mill. Considering the variability of the effluents and that these figures represent only dissolved chemicals, the agreement between the observed chemicals and the amounts used daily is considered good.

River Samples

Water

As indicated earlier, river water samples were collected to make eight weekly composites at each of the stations. Table III indicates the results of gross radioactivity and radium analysis of these samples as averages for the eight survey weeks.

The gross radioactivity and dissolved radium at the three background stations (1, 3, and 12) were consistently low. As shown, they increased sharply below the mill at Station 2 and then decreased progressively to Farmington. Stations 10 and 11 provide some indication of the amount of suspended activity discharged by the mill, and it is especially important to note that essen-

TABLE III.—Radioactivity of River Water

Sta.	River	Mileage Below Mill	Radioactivity ($\mu\mu$c/l)					
			Alpha		Beta		Dissolved Radium	
			Diss.	Susp.	Diss.	Susp.	Average	mg/day
1	Animas	−1.0	2	<1	40	6	0.6	0.54
12	Lightner Cr.	−0.2	5	~0	30	~0	0.3	—
11	Lightner Cr.	0.03	190	3,200	530	3,700	49	—
10	Animas	0.05	150	5,200	270	6,600	40	—
2	Animas	2.0	85	35	115	55	12.6	11.5
4	Animas	23	60	15	130	25	7.2	7.2
3	Florida	—	3	3	40	~0	0.3	0.02
5	Animas	28	65	15	150	32	7.6	8.0
6	Animas	59	30	3	80	10	2.9	1.6

tially all of this material settled to the river bed above Station 2.

Dissolved radium as mg/day passing a given station was obtained by use of the individual weekly average radium concentrations and the corresponding flows of Table II.

Table III shows that between Stations 1 and 2 about 11.0 mg/day of dissolved radium was added to the river water. This quantity decreased only slightly between Station 2 and the Colorado-New Mexico State line, Station 5, the Florida River adding a negligible amount. Below the State line large quantities of Animas River water are used for crop irrigation. As a result, the total flow in the river was markedly reduced by the time it reached Station 6, Farmington. Also, return irrigation flow tended to dilute the remaining river water and thus helped to reduce radium concentrations. By these effects, the quantity of radium in mg/day passing Station 6 was markedly less than at the State line. This reduction may also have been aided by radium removal from the water by biological uptake, and possibly by precipitation.

As has been indicated, the quantity of dissolved radium released by the direct mill effluents cannot account for the quantity found in the water at Station 2, just 2.0 miles downstream. Measured dissolved radium discharges in the mill effluents amounted to only 0.3 to 0.8 mg/day, whereas an observed gain of 11.0 mg/day was noted at Station 2. On the other hand, the mill discharged larger quantities of radium in the undissolved state. As noted previously, these discharges amounted to probably 30 mg/day. It has been seen that the bulk of these undissolved mill solids settled out in the river above Station 2. This daily discharge of undissolved radium, depositing above Station 2, may be viewed as forming a reservoir of radium for subsequent dissolution and appearance as dissolved radium at Station 2 and downstream. This is borne out, as will be seen, by the analyses regarding radium content of river muds. Thus it appears that the large fraction of dissolved radium in the river water comes not from direct discharges by the mill, but rather from the reservoir of undissolved radium on the river bed.

Selected river water samples were also assayed for uranium at Stations 2 and 5, and indicated that the river below the mill commonly carried from 260 to 300 lb/day of dissolved uranium. The mill effluent data, and subsequent analysis of some later river samples demonstrate that essentially all of this uranium results from dissolved and undissolved uranium in the mill effluents. While it is not hazardous in terms of the MPC for uranium, it does constitute a substantial financial loss to the mill.

It is also of interest to note that such quantities of dissolved uranium add considerably to the dissolved gross alpha activity of the river water. Specifically, at Stations 2 and 5 about 60 per cent of the dissolved gross alpha activity was due to uranium.

Strontium-90 analysis of selected river water samples indicated a level of about 0.8 $\mu\mu$c/l, with no significant difference between stations.

Table IV indicates the chemical quality changes in river water after release of the mill effluents. The increase in sulfates, chlorides, and sodium below the mill at Stations 2 and 5 is evident, as are slight increases in arsenic and vanadium.

Bacteriological tests at three different times indicated the general effects of addition of domestic sewage at Durango and in New Mexico, but did not show serious pollution of this nature. Dissolved oxygen below Durango was more than 8.0 mg/l until Farmington was reached. BOD added at Durango amounted to only about 1.5 mg/l of ultimate first-stage demand, a maximum of only 3.4 mg/l being reached

TABLE IV.—Chemical Content of River Water

Chemical	Concentration (mg/l)		
	Station 1	Station 2	Station 5
Sulfate	113	151	141
Chloride	21.6	33.8	30.8
Sodium	24.8	48	48
Iron	<0.02	<0.02	<0.02
Manganese	<0.075	<0.075	<0.075
Zinc	0.040	0.070	<0.019
Copper	<0.025	<0.025	<0.025
Beryllium	0.085	0.04	0.01
Arsenic	<0.016	0.056	0.056
Selenium	<0.002	0.0025	0.0025
Cadmium	<0.004	<0.004	<0.004
Lead	<0.02	<0.02	<0.02
Vanadium	<0.002	0.008	0.006
Fluoride	0.44	0.42	0.42

at Station 2. At Farmington about 3.0 mg/l of ultimate first-stage demand was added.

Muds

Table V shows the average radioactivity of river muds obtained at the six primary sampling stations. A total of 4 samples is included for each station, one every other week for four weeks. Two samples from Station 10 averaged 590 $\mu\mu c/g$ of radium, but are not considered representative of the river cross-section.

As may be seen, an appreciable amount of radium had been deposited on the river bed in the first two miles below the mill, and the radium content of mud at the Colorado-New Mexico line was still more than 20 times the natural background amount.

TABLE V.—Radioactivity of River Muds

Station	Mileage Below Mill	Radioactivity ($\mu\mu c/g$)*		
		Gross Alpha	Gross Beta	Radium
1	−1.0	18	110	1.7
2	2.0	1,250	1,350	171
3	(Tributary)	17	70	1.5
4	23	395	450	52
5	28	285	430	37
6	59	42	83	7.0

* Dried weight.

Laboratory tests with water and radium-bearing mud supported the conclusion that such muds act as radium reservoirs on a stream bed and can be expected to contribute dissolved radium to the flowing water. It was found that from 0.1 to 1.0 per cent of the radium in the mud could be dissolved out with brief mixing. In any specific case the degree of radium dissolution depends apparently on the intimacy and duration of the water-mud contact, or, in a stream, on the velocity and degree of turbulence and bottom scour. This leads at once to the probability that the dissolved radium in the water will increase, rather than decrease, with ascending river flow, assuming a constant daily deposit of undissolved radium. While the available data are not yet sufficient to prove this hypothesis, the available results do support it. Considering a daily deposit of 30 mg of radium above Station 2, and the above range of solution percentages, it is a simple matter to demonstrate the accumulation of at least a gram of radium in the muds and the presence as a result of 10 mg/day of dissolved radium passing Station 2. Conservative computations based on the observed data indicate this much undissolved radium to be present in the muds above Station 2.

The average strontium-90 content of 3 river mud samples was 0.4 $\mu\mu c/g$ of ashed material, about the same as the content of farm topsoil samples.

Aquatic Biota

Table VI presents the data regarding gross radioactivity and radium content of river algae and aquatic insects for the six primary sampling points. Results are per gram of ashed material, and represent 4 biweekly samples for each station.

The gross alpha activity of algae at Station 2 was 100 times or more

TABLE VI.—Radioactivity of Aquatic Biota

Station	Radioactivity ($\mu\mu c/g$)					
	Algae			Insects		
	Alpha	Beta	Radium	Alpha	Beta	Radium
1	23	450	4.8	30	880	4.2
2	3,910	5,760	390	1,820*	4,110*	71*
3	33	640	4.3	11	430	3.4
4	1,520	2,160	150	1,190	2,260	160*
5	910	2,010	90	360	830	68*
6	120	290	26	75	400	15

* Single result.

greater than the natural alpha background, and 50 times greater at Station 4. At the State line (Station 5) the gross alpha activity of algae was still 30 times background, and diminished to about 5 times background at Farmington (Station 6). Radioactivity of the bottom insects was quite similar.

The radium content of algae closely parallels their gross alpha radioactivity, showing a gain by a factor near 100 at Station 2, and diminishing progressively downstream to about 5 or 6 times background radium at Station 6. Bottom insect samples analyzed so far generally reflect the same picture as the algae.

Only minnow samples have been analyzed for gross radioactivity. On the average, the gross alpha radioactivity of minnows at Stations 1, 2, and 5 paralleled that of algae and insects.

Three samples of algae and two of insects contained an average of 0.4 $\mu\mu c/g$ ash of strontium-90.

An additional collection of algae and mud samples made in early April 1959, contained somewhat greater concentrations of radium at stations below the mill. These samples reflected an extended low flow period in the river that had lasted for several winter months. It was very difficult to wash the algae free of silt, and they must be considered as algae-silt samples. Nevertheless, as may be seen in Table VII, the radioactivity and radium contents were markedly higher than either the algae or silt samples collected during the summer of 1958 (see Tables V and VI). Results are per gram of ashed material in the case of algae, and the gross radioactivity of muds are reported for purposes of comparison. Radium analyses of water and muds were not available at the time of this report. Flow in the Animas did not rise above 250 cfs for the 3 months preceding these samples.

Water Plants

As noted earlier, composite samples of both raw and treated water at the Aztec and Farmington, New Mexico, water treatment plants were collected during the survey. Similar samples of raw water were collected at the Shiprock, New Mexico, water treatment plant. All of these water treatment

TABLE VII.—Radioactivity of Algae and Mud, April 1959

Station	Radioactivity ($\mu\mu c/g$)		
	Algae	Mud	
	Radium	Alpha	Beta
1	3.3	9.7	35
2	880	4,300	3,100
4	500	1,450	1,700
5	390	840	1,320
6	100	340	340

plants employed conventional methods of water treatment, including sedimentation, addition of chemicals, rapid sand filtration, and chlorination. None of them used water softening. Aztec obtained its raw water supply from a ditch diversion taking water from the Animas about three miles above Aztec. Farmington's water supply was in part from a ditch taking water from the Animas above Aztec, and in part directly from the Animas at Farmington. Shiprock took its water part of the time from the San Juan via a ditch diversion 12 miles east of the town and directly from the river near Shiprock at other times.

Table VIII presents the average data for the eight weeks of composite sampling of water supplies. Station 5 is included because it most nearly reflects the quality of water available to New Mexico raw water users. Stations 7, 8, and 9 refer to Aztec, Farmington, and Shiprock, respectively, and the letters "R" and "T" indicate either raw or treated water.

It is apparent from Table VIII that the water treatment plants at Aztec and Farmington do not remove dissolved radium from the raw water during treatment. Whatever dissolved radium occurs in the raw water must be expected to pass unchanged to the treated water. This apparently is true for other alpha emitters.

In terms of natural background concentrations of dissolved radium, the dissolved radium content of the raw waters at Aztec and Farmington was 5 and 6 times higher than background amounts as measured on the Animas at Station 1, and 10 times higher than background as measured on the Florida River, on Lightner Creek, or for that matter on the San Juan below its confluence with the Animas (Station 9R). During the 1958 survey period the radium content of the raw and treated waters at Aztec and Farmington approached the MPC for radium (5)(6). In terms of population exposure the summer of 1958 was relatively wet in terms of flows in the Animas, and the available dilution for wastes was, therefore, somewhat higher than in other years and other seasons. This effect will be discussed in some detail at a later point.

TABLE VIII.—Radioactivity of Water Supplies

Station	Radioactivity ($\mu\mu$c/l)				
	Alpha		Beta		Dissolved Radium
	Dissolved	Suspended	Dissolved	Suspended	
5	65	15	150	32	7.6
7R	36	10	90	36	3.4
7T	38	1	78	4	3.6
8R	32	4	90	11	2.8
8T	32	0	67	0	2.6
9R	8	0	50	0	0.4

As regards raw water users below the Colorado-New Mexico State line, the quality of water at Station 5 averaged 7.6 $\mu\mu$c/l of dissolved radium, or about 12 to 25 times the natural background amount, and about twice the MPC (5)(6). As has been noted, the available dilution at Durango was higher during the survey than in other summers.

Radium concentrations noted here reflect the effects of irrigation water diversion and return. As indicated by other data, this apparently resulted in marked reduction of dissolved radium between the State line and Farmington. It is quite doubtful that the radium concentrations below the State line would be so significantly reduced during the non-irrigation seasons, and it appears likely that during the non-irrigation part of the year radium concentrations at the Aztec and Farmington raw water intakes will much more nearly approach the concentrations observed at the State line. This is borne out to good degree by the data regarding radium concentrations above the State line. Although some irrigation water is diverted in Colo-

TABLE IX.—Radioactivity of Filter Sands

Station	Place	Radioactivity ($\mu\mu c/g$)		
		Alpha	Beta	Radium
7	Aztec	45	117	27
8	Farmington	32	125	4.7
9	Shiprock	40	123	2.6

rado, most is taken in New Mexico, and the return irrigation water flow above the State line is only slight. Hence, it appears that irrigation practice in New Mexico during the warmer months aids materially in protecting the New Mexico water supplies as regards their radium content.

Samples of sand from the filters at the Aztec, Farmington, and Shiprock water treatment plants were collected three times during the summer and analyzed for gross radioactivity and for radium. The results are noted in Table IX. It is apparent that the filter sands in use at Aztec contained relatively larger quantities of radium, about six times the amount in those at Farmington. The latter contained about three times the amount of radium found in river muds (see Table V) above the uranium mill on the Animas and on the Florida River.

It is of interest to note from Table VIII that, although the difference is slight, the treated water for Aztec showed slightly more dissolved radium on the average, than did the raw water. The reverse was true for Farmington. This and the data of Table IX indicate the likelihood that radium trapped in water plant sand filters will dissolve out in part into the treated water.

Analysis for radium of the suspended solids in the Aztec and Farmington water supplies demonstrated the presence of some radium-bearing solids in the Aztec water supply but not in the Farmington supply. The suspended solids from monthly composite samples for October, November, and December 1958, contained an average of 3.3 $\mu\mu c$ of radium per liter of raw water at both Aztec and Farmington; at Aztec, the tap water averaged 0.13 $\mu\mu c$ suspended radium per liter, whereas at Farmington the three monthly composites of treated water all contained 0.0 $\mu\mu c$ of suspended radium. The radium content of the suspended solids averaged 40 $\mu\mu c/g$ and 21 $\mu\mu c/g$ for Aztec and Farmington raw waters, respectively, and 6.4 and 0.0 $\mu\mu c/g$ for the respective tap waters.

Raw water samples from Aztec and Farmington contained an average of 1.6 $\mu\mu c/l$ of strontium-90, while the average strontium-90 content of treated waters was 1.0 $\mu\mu c/l$. These levels were well below the permissible amount of 80 $\mu\mu c/l$. (5)(6).

Milk Samples

Table X indicates the results of analysis of the routine monthly milk samples collected at Farmington, New Mexico, from August 1958 through April 1959.

The data of Table X reflect the occurrence of nuclear weapons tests during 1958 as well as their absence thereafter. Except for the single high result for radioiodine, the milk supply for the Farmington area contained intermediate amounts of radioactivity as compared to other American cities (13).

TABLE X.—Radioactivity of Milk

Collection Date	Gross Beta $\mu\mu c/g$ of ash	Radioactivity ($\mu\mu c/l$)				
		I^{131}	Sr^{90}	Sr^{89}	Ba^{140}	Cs^{137}
8/28/58	208	57	7.3	113	28	38
9/17	179	19	4.4	62	15	49
10/10	183	11	2.2	70	8	27
10/31	248	1,370	6.5	117	142	28
12/1	203	13	7.9	70	36	46
1/2/59	183	0	6.5	24	9	32
2/4	188	5	3.8	22	0	29
3/3	184	0	4.9	13	0	31
3/31	201	0	7.5	24	0	28
4/24	194	0	12.2	38	0	46

One sample, that collected on August 28, 1958, has been analyzed for radium, and contained 0.37 $\mu\mu$c of radium per liter.

Precipitation

Samples of all of the rains that fell in Durango and Farmington during the two-month 1958 survey were analyzed for gross activity. For the eight samples from Durango dissolved gross alpha and beta activity ranged from 0 to 11 and from 50 to 9,400 $\mu\mu$c/l, respectively; suspended gross alpha and beta radioactivity ranged from 2 to 15 and from 140 to 6,700 $\mu\mu$c/l, respectively. Eleven rains at Farmington contained from 0 to 9 and from 180 to 18,200 $\mu\mu$c/l of dissolved alpha and beta activity, respectively, and from 1 to 11 and from 250 to 8,500 $\mu\mu$c/l, respectively, of suspended alpha and beta activity. All were counted within two days after collection.

The strontium-90 content of four of the Durango rains ranged from 0.7 to 5.3 $\mu\mu$c/l, and the strontium-90 content of four of the Farmington rains ranged from 3.1 to 23.0 $\mu\mu$c/l. The strontium-89 content of the Farmington rains was 10 times their strontium-90 content.

Vegetable and Crop Samples

The radium and strontium content of a variety of crops from the survey area are shown in Table XI. All samples represent crops of August and early September. In general, they were all washed and cleaned in the laboratory, and grains were husked before analysis.

As may be seen, the radium content of foods ranged between 0.7 and 7.6 $\mu\mu$c per kilogram of live material, excluding the alfalfa, which is not consumed by humans. The alfalfa contained from 12.0 to 27.5 $\mu\mu$c of radium per live kilogram. The strontium-90 content ranged from 2.5 to 315 $\mu\mu$c per live kilogram in 28 samples, ex-

TABLE XI.—Radioactivity of Vegetables and Crops

Location and Type	$\mu\mu$c/kg Live Weight		
	Radium	Sr-90	Sr-89
(a) Upstream Farms			
Cabbage	1.7	97	—
Lettuce	4.5	19	—
Green pepper	2.2	—	—
Cucumber	1.0	—	—
Squash	1.3	4.9	—
Tomato	1.2	2.5	8.6
Sweet corn	0.7	—	—
Sweet corn	1.5	3.1	—
Potato	0.9	—	—
Potato	—	4.1	7.1
Wheat (husked)	7.2	4.8	88
Oats (husked)	1.2	—	—
Pears	1.3	—	—
Apples	1.3	—	—
Alfalfa	13.0	62	705
(b) Downstream Farms			
Cabbage	3.8	315	6.4
Cabbage	2.0	225	74
Cabbage	—	120	—
Lettuce	5.5	970	13,400
Green pepper	4.8	—	—
Green pepper	—	4.3	2.5
Cucumber	1.8	10	23
Squash	1.5	7.7	—
Squash	1.9	5.6	0.0
Squash	1.6	—	—
Tomato	—	10	2.0
Sweet corn	—	2.6	0.0
Sweet corn	—	18	1,470
Field corn	2.4	—	—
Field corn	3.4	—	—
Potato	—	5.4	—
Carrot	3.9	12	—
Carrot	5.9	—	—
Beet	—	8.7	—
Onion	—	8.6	—
Okra	5.0	9.4	—
Peas	—	250	—
Green beans	—	24	135
Wheat (husked)	6.5	—	—
Oats (husked)	6.7	14	—
Pears	6.8	3.6	19
Apples	1.8	66	—
Apples	2.0	—	—
Peaches	5.8	—	—
Peaches	7.6	—	—
Peaches	—	5.9	—
Alfalfa	12.0	9.2	—
Alfalfa	27.4	—	—

cluding alfalfa and the single high lettuce result of 970 $\mu\mu$c/kg. Strontium-89 ranged from 0.0 to 1,740 $\mu\mu$c/kg exclusive of the high lettuce result.

General practice regarding allowable amounts of radioisotopes in food is to apply the MPC's for water to food on a live weight basis. Thus, the allowable amounts of radium and strontium-90 for food would be 4.0 and 80 $\mu\mu$c per kilogram of live material, respectively. In viewing the data of Table XI, however, it must be borne in mind that the real desire is to minimize the quantity of any radioisotope taken in daily. Thus, for example, the concentration of radium in a particular food, say peanuts, may be quite a bit higher than 4.0 $\mu\mu$c/kg, but the quantity of peanuts eaten daily may be small. In that event the quantity of radium ingested daily via peanuts would be small. In the same sense, another individual might consume large quantities of peanuts, and in that case the daily radium intake would be significant.

The allowable concentrations noted above for radium and strontium-90 in food are useful as one index of whether these radioelements are present in significant amounts or not. These numbers are exceeded, at least slightly, in a number of the samples of Table XI. In order, therefore, to make a more precise interpretation of the significance of the data of Table XI, estimates of the average daily quantity of radium and of strontium-90 ingested are needed. These estimates have been made, and are presented later.

Table XI contains sufficient data for some comparison of the radium content of foods from farms located upstream and downstream from the Durango uranium mill. Excluding alfalfa, 11 kinds of sample (e.g., cabbage, green pepper, etc.) were collected at both upstream and downstream locations. Considering only those sets, the data indicate an average radium content of 2.0 $\mu\mu$c per kilogram of live material for farms upstream, against an average concentration of 3.6 $\mu\mu$c per kilogram for downstream farms irrigated with Animas River water. In other terms, the radium content of foods grown downstream was nearly double that of foods from north of the mill.

Chemical Pollution

In order to evaluate the toxic strength of waste discharges from the uranium ore refinery, studies of the aquatic biota were performed in the late summer of 1958. They consisted of a census of bottom-dwelling insects at the several river sampling stations and a series of bio-assay tests of the mill effluents to determine their toxicity to fish. Details of these studies are available elsewhere (10), but a summary of their salient results is presented below.

Bottom Fauna Studies

The aquatic insects, algae, and other organisms that inhabit a river bed are important sources of fish food, and the reduction of this source of food by waste discharges can seriously limit the fish population in the affected stream reach. A census of the bottom-dwelling populations of the Animas River and its tributaries, Lightner Creek and the Florida River, was made in September 1958, utilizing river sampling stations along a 65-mile reach. Reference to Figure 1 will indicate the reach studied and the sampling stations.

Of the sampling devices tried, the most successful was a copper wire screen which was one square yard in area and had 14 wires per inch. The screen was supported at two opposite sides by wood strips, 1 by 2 in. by 4 ft. The screen was placed in the stream so that one edge of the screen rested on the bottom. The screen was then held in position with the wood strips so that water passed through the

screen. A one-square yard area immediately upstream from the screen was sampled by wiping the organisms from the rocks and stirring up the bottom. Detached organisms were carried in the current and deposited on the screen. The screen was lifted from the water and organisms removed with forceps and placed in marked vials. Later, organisms were identified, counted, and weighed.

The area of stream bottom sampled varied from one to several square yards. If organisms were numerous, one square yard was sufficient to indicate the relative abundance and the number of representative kinds. Several square yards were sampled where organisms were scarce.

Figure 4 is a graphic presentation of the bottom fauna collection data. Populations of bottom fauna were similar in the Animas, the Florida, and Lightner Creek where these streams were not affected by mill wastes. Below the mill (Station 2) a sharp reduction of bottom organisms, nearly to complete elimination, is evident. The Animas was adversely affected well below the State line (Station 5). Initial recovery was indicated 36 miles below the mill, where the number of species increased, but where numbers of organisms remained low. Not until the river had flowed some 45 miles below Durango did the bottom fauna population approach normal proportions.

Bio-assay Studies

Bio-assay tests of the several effluents and process wastes from the Durango ore refinery were performed during September 1958, to determine the toxicity of the effluents to test fish. In such tests, the wastes, collected within the plant prior to discharge to the river, are diluted with appropriate amounts of river water, and the concentrations are determined which will kill one-half of the test fish in a specified period of time. These tests, conducted in the laboratory, simulate natural river conditions. They provide sufficiently accurate measures of the tolerance of fish to the wastes so that estimates can be made of the amount of river dilution

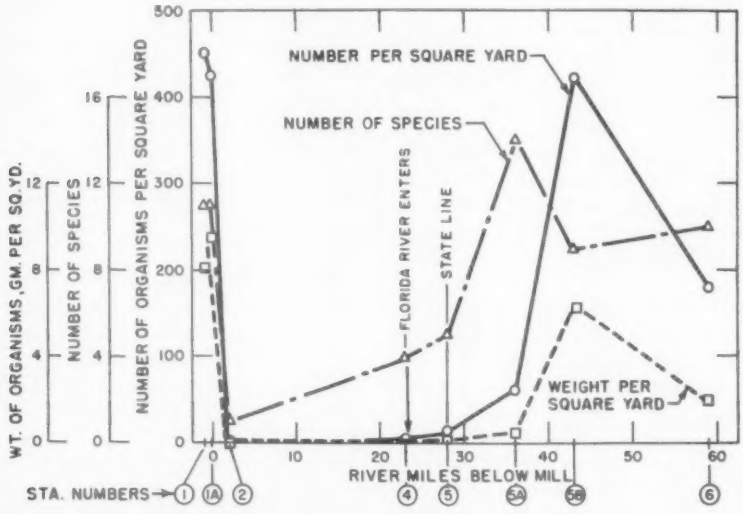

FIGURE 4.—Results of bottom fauna studies.

water needed to prevent the wastes from harming the fish in the stream.

In this case, the test fish were rainbow trout, and the wastes tested included the main plant effluent, the tailings pond effluent to Lightner Creek, the organic raffinate, the vanadium filter tray wash water, and the primary tails effluent. The tests were conducted at the Colorado Game and Fish Department hatchery at Durango, in accordance with generally accepted procedures (14), and test fish were obtained from the rearing ponds at the hatchery. Details of the test procedures and results are available in the general report of the survey (10).

In brief, test fish were exposed to various concentrations of the particular waste, diluted with unpolluted Animas River water, to determine the median tolerance limit (TL_m).

Since the TL_m value is the waste concentration in which only 50 per cent of the fish will survive the specified exposure period, lower concentration must prevail if all fish are to survive indefinitely. The observed TL_m value is, therefore, reduced by an application factor which is used in computing dilution requirements for the particular waste. The best application factor is also dependent on sensitivity of the fish or fish food organisms to be protected, variability of the waste, temperature, pH, and chemical characteristics of the river water. The application factor, as a result, may be from one-third to one-tenth of the TL_m concentration (15).

Composite samples of the main effluent had 72-hr TL_m values of 0.44 and 1.5 per cent, indicating that a concentration of as little as 0.44 per cent of this waste stream would kill 50 per cent of test fish. Samples of the tailings pond effluent to Lightner Creek had 72-hr TL_m values of 1.3 to 3.7 per cent.

The primary tails effluent was the least toxic plant waste, having a TL_m of 13 to 18 per cent for a 72-hr exposure. The vanadium filter tray wash, another component of the main effluent, had 72-hr TL_m's from 1.0 to 4.2 per cent. The organic raffinate, also a part of the main effluent, was the most toxic waste liquor, having 72-hr TL_m's of 0.09 to 0.21 per cent waste. This waste had the greatest effect on the toxicity of the main effluent.

Other exposure periods were used and reported in the general survey report, but the above results were typical (10).

As an example of the means of estimating dilution requirements, the main effluent, having a 72-hr TL_m of 0.44 per cent and a flow of 270 gpm, or 0.60 cfs, may be considered. A river flow of 136 cfs would provide just enough dilution to result in a waste concentration of 0.44 per cent in the river. Selecting the minimum application factor of one-third, at least 408 cfs of flow in the river is necessary to prevent harm to the river biota and fish. The effluent to Lightner Creek, having a 72-hr TL_m of 1.8 per cent and a flow of 93 gpm, or 0.21 cfs, would similarly require a river dilution flow of 33 cfs to prevent harm. Thus, the two direct effluents to the Animas would on this basis require a total of at least 441 cfs in the river to prevent harm to the aquatic biota.

On the basis of these and similar computations it has been estimated that a total flow in the Animas River at Durango of 600 cfs would be required at times to protect the aquatic life. As has been noted, the flow in the river is well below this level for much of any year. In the summer of 1958 flows dropped to about half this figure, with resulting observed sharp reduction of bottom and fish populations.

Human Internal Radiation Exposure

As has been indicated, the total quantity of any radioisotope ingested daily, rather than its concentration in

any medium such as water or food, is the desired measure of internal radiation exposure. Much of the data reported here can be interpreted in terms of the quantities of radium and strontium ingested daily by people of the Durango-Farmington area. As the means of interpretation in terms of existing recommended standards, the permissible daily intakes of radium, and of strontium-90 have been computed on the basis of their MPC's in water. Thus, radium has an allowable concentration of 4 $\mu\mu$c/l and that for strontium-90 is 80 $\mu\mu$c/l. Handbook 52 indicates that these concentrations are based on an average consumption of water of 2.2 liters per person per day. Hence it has been calculated that the total allowable daily intakes of radium and of strontium-90, via any path (water, food, air, etc.) are 8.8 and 176 $\mu\mu$c per person per day, respectively. The observed radium and strontium-90 levels in the various kinds of medium are interpreted in terms of these figures.

Four classes of exposed individuals are indicated by the available data. The group receiving the greatest exposure consists of those consuming untreated Animas River water taken from the river below the mill and in the vicinity of the Colorado-New Mexico State line. Consumption of crops raised with similar Animas River irrigation water adds to this exposure. A second exposure group consists of those using treated water at Aztec, New Mexico, and a third comprises individuals using treated Farmington, New Mexico, water. Finally, the Durango, Colorado, population group, using unpolluted water, makes up the control, whose exposure is at a minimum.

Table XII presents a summary of the estimated total exposure of these population groups resulting from ingestion of radium and of strontium-90. The figures are in terms of fractions of the maximum permissible daily intake. For example, as found in the 1958 survey, those consuming raw river water from the vicinity of the State line were ingesting daily about 1.90 times the permissible radium intake solely through their water supply; they received only about one per cent of the allowable strontium-90 exposure from their domestic water. Added to this, if they consumed largely locally raised foods, they ingested daily about 50 per cent of the allowable radium intake and 22 per cent of the allowable strontium-90 intake. Adding these figures, this group was receiving on the average 2.63 times the allowable exposure to the bone-seekers, radium and strontium-90. On this same basis, should the mill capacity increase to 700 tons of ore per day, waste flows would presumably increase accordingly. If waste treatment practices remained unchanged, the concentrations of radium in the river, and the resulting exposure, would rise as shown, and the people using raw river water would ingest on the average an additional 69 per cent of the allowable amount of radium. Other population exposures would be modified as shown.

Details of the computations and assumptions involved in these estimates are provided elsewhere (10). In brief, for water flows and conditions as of the 1958 survey, the concentrations of radium and strontium-90 as reported here were used directly. Thus, for example, the radium concentration at Station 5 averaged 7.6 $\mu\mu$c/l over the two-month survey, and this amounts to 1.90 times the allowable concentration of 4.0 $\mu\mu$c/l (Table XII). Observed concentrations of radium at the Aztec and Farmington water plants were used for those group estimates, and for Durango the radium burden of the unpolluted Florida River was representative.

In order to estimate the radioactivity intake via food and milk, a typical

TABLE XII.—Summary of Estimated Exposures in Fractions of the Allowable Amount

Source of Radioactivity	As found in 1958 Survey				In a Water Year like 1955–56			
	Durango	Raw	Aztec	Farm.	Durango	Raw	Aztec	Farm.
Radium in water	0.08	1.90	0.90	0.65	0.08	2.82	1.82	1.46
Strontium-90 in water	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Radium in food and milk	0.28	0.50	0.50	0.50	0.28	0.50*	0.50*	0.50*
Strontium-90 in food and milk	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Totals	0.59	2.63	1.63	1.38	0.59	3.55	2.55	2.19
Increase due to planned mill capacity expansion†	0.00	0.69	0.33	0.24	0.00	1.02	0.66	0.53
Totals	0.59	3.32	1.96	1.62	0.59	4.57	3.21	2.72

* No increase included for higher radium concentrations in irrigation water.

† Increase of 36 per cent in water radium concentrations for planned mill expansion from 514 to 700 tons of ore per day.

moderate cost diet for physically active men was used (16) in conjunction with the observed radioactivity of foods as shown in Table XI. Detailed computations were made for upstream and downstream farms separately, and for separate types of food. For example, the weekly consumption of leafy green vegetables was given as 3.75 lb/wk (16) and for downstream farms the average radium content of leafy green vegetables was estimated to be 1.91 $\mu\mu$c/lb, making a daily radium intake of 1.0 $\mu\mu$c. No data were obtained regarding the radium or strontium-90 content of meat, poultry, fish, eggs, dried beans, peas and nuts, fats and oils or sugar, syrups, and preserves. Hence, for these purposes zero intake of radium and strontium-90 was assumed for those specific foods, in order to assure conservative results.

Based on the foregoing assumptions and computations, consumption of local crops and milk would involve the daily ingestion of 4.4 $\mu\mu$c of radium and 39 $\mu\mu$c of strontium-90 for downstream farms. For upstream farms the figures are 2.5 $\mu\mu$c of radium and about the same 39 $\mu\mu$c of strontium-90. These figures are reflected as fractions of the allowable daily intake in Table XII.

In general practice, radiation exposures are estimated on an annual average basis in order to avoid short-term variability, and hence Table XII also shows estimated exposures for a water year like 1955–56, the last published record of the U. S. Geological Survey. Flows in the Animas during that year were somewhat lower than those observed in 1958, and the flow at Durango had a return period of three to four years according to the flow frequency studies. Although it might be expected that other intake figures would also be affected by lower flows and less dilution, only the figures for radium in water were altered in this computation, in order to remain conservative.

These computations for a water year like 1955–56 were based on the observed 8.0 mg/day of dissolved radium passing Station 5 during the 1958 survey. Using this basic quantity, radium concentrations were computed at the points of interest on a daily basis for the entire 365 days, using the daily average flows reported by the U. S. Geological Survey. As has been noted, irrigation practice probably protects the Aztec and Farmington water supplies somewhat during part of the year, while an extended low flow pe-

riod occurs in the river during the cold winter months. As a result, during the winter months radium concentrations at Aztec and Farmington are probably not reduced to the extent that was observed during the 1958 irrigation season, and allowance for this effect has been incorporated in these computations. Preliminary data for later 1958–59 samples indicate that this assumption is correct.

These estimates must also be interpreted in terms of the fact that most of the radium dissolved in the Animas water has its source in the bottom deposits of radium-bearing mill solids, as has been shown earlier. The figures given indicate that radium in river muds was 3 to 4 times higher in April 1959 than observed during the summer of 1958. This, of course, was due to the fact that the winter months of low flow provided a longer period for undisturbed accumulation of bottom deposits before the spring floods flushed them downstream. From this view, therefore, it is most probable that radium concentrations at water intakes were higher during the winter and early spring than has been assumed, and preliminary data on later samples substantiate this.

In addition, it is clear that the amount of radium dissolved in the flowing stream depends heavily on the intimacy and violence of contact between the flowing water and the river muds. In other terms, the higher flows with their increased velocities and turbulence should result in higher dissolved radium concentrations in the flowing water. This effect counteracts the assumption that higher flows provide more dilution and, therefore, cause lower concentrations. Again, it is substantiated by preliminary data on 1959 samples. For this reason also, then, the estimated radium exposures for a water year like 1955–56 may well be too low.

Certain other sources of internal radiation exposure exist in the Durango-Farmington area, but were not susceptible to measurement or analysis at the time of survey. No attempt was made to estimate the occupational exposure of workers at the uranium mill. No measurements were made to evaluate the effects of air pollution in the vicinity of the mill. Other bone-seeking radioisotopes occur also in fallout, but no attempt was made to measure their concentrations, as it was believed their effect would be negligible compared to radium and strontium-90. The effects of watering stock in the Animas River or its irrigation ditches, together with the use of radium-bearing alfalfa, has been neglected as a source of internal radiation exposure, as has been any effect of grazing cattle on irrigated land except insofar as this would place strontium-90 in the milk. Many or most of these additional sources of exposure may well be relatively minor.

It must be emphasized that the figures regarding internal radiation exposure are averages for the area, and must be interpreted in that sense. It is probable, therefore, that significant deviations from them occur as far as individuals and individual families are concerned. Thus some individuals may ingest less and others more radioactive material than the averages indicate, depending on individual daily intake of water and milk, the types and quantities of food consumed, specific location of the irrigated farm, and other individual and local differences.

It should also be recalled, in interpreting the results presented here, that the allowable daily intake of radioactive material refers to that amount which can be ingested continuously over a lifetime without producing any readily detectable biological damage. Hence, ingestion of any particular radioisotope in amounts somewhat higher than the allowable for relatively brief periods of time may not result in undue harm.

Remedial Measures

On June 24, 1959, the foregoing facts regarding pollution of the interstate waters of the Animas River were presented at a second session of the Conference on this matter initiated under Public Law 660 in April 1958. Representatives of Colorado, New Mexico, the Public Health Service, the uranium company, and all other interested agencies, local and Federal, were present. As a result of the discussions at that meeting there was agreement that:

1. The pollution of the Animas River caused by discharges of uranium milling wastes from the uranium ore refinery at Durango, Colorado, deleteriously affected public water supplies at Aztec and Farmington, New Mexico, individual water supplies of ranchers, and others who take raw water from the river, water used for irrigation, fishing, swimming, and stock watering in New Mexico.

2. Discharges of nonradioactive chemicals to the Animas River by the uranium mill at Durango, Colorado, were toxic to fish and aquatic life in the Animas River and such discharges created conditions inimical to such fish and aquatic life.

3. Cognizance should be taken of the cordial cooperation that officials of the uranium company at Durango, Colorado, extended to the public agencies to achieve a solution to this problem and to facilitate necessary analyses and studies; and cognizance should be taken of the progress and planning toward solution of the pollution problem by the company since the first session of the Conference.

4. The company would take the following action at its uranium mill at Durango, Colorado, by October 24, 1959: (*a*) install treatment facilities which will substantially remove all settleable solids in order to reduce radioactive discharges to the Animas River, (*b*) install facilities that will treat the remaining radioactive material in solution in the plant effluent by a process which will reduce the remaining soluble radium content of the effluent by at least 70 per cent, and (*c*) install treatment facilities which will reduce discharge of toxic materials deleterious to fish and aquatic life so that these materials will no longer be discharged into the Animas River in quantities harmful to such fish and aquatic life.

5. As soon as practicable after October 24, 1959, representatives of the Public Health Service and the State water pollution control agencies of Colorado and New Mexico will make a joint investigation and evaluation of the remedial facilities put into effect at the uranium ore refinery and report thereon to the conferees and other interested parties.

In a recent news release on this subject (17), the Secretary of Health, Education, and Welfare has stated:

> I am happy to report that the first Federal enforcement action to control contamination of interstate waterways by radioactive wastes has now reached a successful conclusion through voluntary agreement.
>
> This first enforcement action involving radioactive pollutants in water is significant for several reasons:
>
> 1. It sets a precedent for maintaining high standards in the control of radioactive wastes and human radiation exposure. Although by merely extracting solid particles of radium from the wastes discharged into the river, radioactivity would have been materially reduced, the agreement goes beyond this and includes removal of all radium that can be removed by known methods.
>
> 2. The value of the 1956 law authorizing the Public Health Service to undertake pollution surveys of all interstate streams and to institute anti-pollution procedures has been dramatically demonstrated.
>
> Because the law permits the Public Health Service to conduct water pollution surveys and hold conferences on the abatement of interstate pollution, the situation was brought under control before the population of the area had ingested sufficient

amounts of this radioactive material to cause detectable health damage.

Summary

The foregoing material regarding pollution of the Animas River by long-lived radioactive wastes illustrates by practical example many of the principles of detection, interpretation, and control of this type of water pollutant. In particular, it demonstrates the importance of assessing such wastes in terms of the total human intake of related radioisotopes by all paths of ingestion rather than simply in terms of water concentrations of individual radionuclides.

The nuclear industry is developing at a rather rapid pace in this country. As it develops there will also appear more and more kinds of major radioactive wastes in increasingly large quantities. The problems of waste control will become increasingly complex, especially in terms of knowing the total radiation exposure of affected populations. During the same period it may be anticipated that the recent tendency to make standards for radiological protection increasingly stringent will be continued. In summary, then, it appears that the only acceptable course in the area of radioactive waste control is to keep all radioactive effluent discharges to the environment to a minimum, as has been the advice of the National Committee on Radiation Protection (6)(8). The MPC's should be regarded as maximums rather than numbers to "shoot at," and concentrations should be kept as far below them as possible.

Acknowledgments

The studies reported here were conducted with the full cooperation of the Colorado Department of Public Health, the New Mexico Department of Public Health, the San Juan Basin Health Unit of Durango, Colorado, the San Juan County Health Department of Farmington, New Mexico, the uranium ore refining company, and the U. S. Atomic Energy Commission. They could not have completed without the assistance of these groups.

The authors are especially indebted to the following members of the survey team, who carried out the bulk of the technical work: S. D. Shearer, Jr., R. M. Shaw, J. D. Jones, D. A. Clark, C. E. Sponagle, J. B. Anderson, and D. E. Rushing.

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EUROPEAN SANITARY ENGINEERING COURSE

A European course in sanitary engineering is being organized by the Technological University at Delft and the Netherlands Universities Foundation for International Co-operation (NUFFIC) with the assistance of the Organization for European Economic Co-operation (Paris) and the World Health Organization (Copenhagen). The course will be held from October 19, 1960, to September 14, 1961.

The aim of the course is to provide civil engineers with special training in sanitary engineering to enable them to take part in the struggle with water pollution in the densely populated and highly industrialized area known as Western Europe.

The course will be of 11 months' duration with instruction in the English language. The faculty will consist of experts from different European countries. A number of institutions in different European countries will also collaborate in the course.

The faculty will be headed by Prof. W. F. J. M. Krul, Professor of Sanitary Engineering at the Technological University at Delft, whereas Ir. L. J. Mostertman, director of studies of the International Course in Hydraulic Engineering, will be charged with the daily direction of the course.

The tuition fee for the course is 2,000 Dutch guilders (approx. £ 190).

Closing date for applications is July 31, 1960.

Further particulars are to be found in the prospectus which will be sent on application to NUFFIC, 27, Molenstraat, The Hague, The Netherlands.

REVIEW OF DETERGENT RESEARCH PROGRAM *

By P. J. Weaver

The Procter & Gamble Company, Cincinnati, Ohio; and Member, Research Steering Committee of the Association of American Soap and Glycerine Producers, Inc.

The population growth in this country during the past 10 to 15 years has been, as everyone knows, enormous. It is forecast that in 15 years there will be 220,000,000 people living in this country, where now there are roughly 170,000,000, a rate of growth which is difficult to comprehend. When it is realized that this means each night some 9,000 more persons will sit around the country's dinner table than were there the night before, the figures assume more understandable terms.

Similarly, industry is expanding at a tremendous rate. As a result of both factors, water usage is soaring, and with this the need for additional water and sewage treatment facilities. Yet, according to the Business and Defense Services Administration, the U. S. investment in municipal sewage systems already is at least $6.9 billion short of what it should be, and in waterworks is short by $4.6 billion of the needs (1). This, then, points up some of the reasons for the problems faced by the treatment plant operator and the sanitary engineer today.

These problems are understandable and can be rationalized. It is true that construction of new sewage treatment plants is increasing, as is shown in Figure 1, prepared from published statistical information (2). This construction, however, is not increasing fast enough, and capacity at existing plants is severely strained. With the new types of wastes which the plants must treat today, with undercapacity in many cases, with attempts to develop new and sometimes radical treatment methods so as to handle more capacity in existing facilities, with a real shortage of needed facilities, it is not surprising that problems exist. Indeed, the surprising thing is that such a truly excellent job is being done under these problem conditions.

Reference was made to new types of wastes, to the change in their character during the postwar years. The growth of plastics, fibers, medicinal chemicals, fertilizers, dyes, insecticides, and synthetic organic agricultural chemicals, is well known. Many other examples can be cited as indicative of the over-all trends. While many of these may not appear in straight domestic wastes, there are many that do, and in the combined treatment of industrial and domestic wastes, the problem may be compounded.

Along with this trend, has been the growth in usage of synthetic detergents. These materials have, since World War II, essentially replaced the traditional soaps in the household, with roughly 90 per cent of the sales for home consumption now being of the new detergent type. Thus, where the American housewife used to put soap solutions down the drain, she now puts detergent solutions. As pointed out above, detergents are only one of many new materials appearing in domestic wastes. Nevertheless, their very nature—the fact that they contain surface active agents which foam, that at dishpan (e.g., 600 mg/l) con-

* Presented at the 1959 Annual Meeting, Ohio Sewage and Industrial Wastes Assn.; Cincinnati, Ohio; June 17–19, 1959.

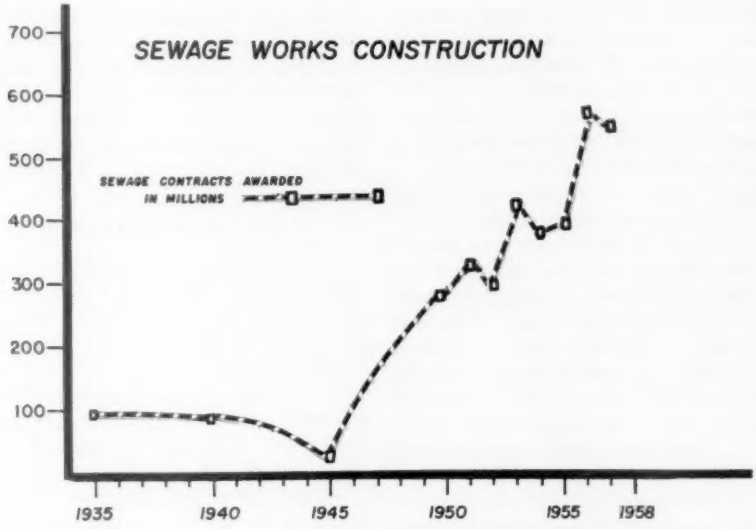

FIGURE 1.—Sewage works construction contracts awarded 1935–1957 (in millions of dollars).

centrations these surfactants can suspend soil—has understandably raised questions in the minds of treatment plant operators when conditions in their plants seemed to relate to these factors.

Research Organization

The detergent industry recognized the significance of these questions, and resolved to (*a*) determine whether any of the reported problems really did concern detergents, and (*b*) help in correcting any problems if it developed that detergents were actually involved. Consequently, the Association of American Soap and Glycerine Producers, Inc., organized and set in motion its research program early in 1954.

It might be believed that an industry association, made up of individual companies which are in direct and strenuous competition with each other in the day-to-day market, might present an unwieldy and almost unworkable combination in attacking a problem such as this. Such is farthest from the case. From the outset the industry has recognized that this is a common problem, to be faced for the common good, not only of the industry, but of the sanitary engineering field and the public as a whole. Consequently, it seems fair to state that this group has been one of the most efficient and effective groups of its type ever formed.

The Soap Association's over-all research program was activated and has been guided largely by the Research Steering Committee of the Technical Advisory Council. This committee is now made up of 10 companies: Monsanto Chemical Co., Lever Brothers Co., Atlantic Refining Co., Calgon Co., California Research Corp., Colgate-Palmolive Co., Continental Oil Co., Victor Chemical Works, Westvaco Mineral Products Div., and Procter & Gamble Co. To initiate an outside research project the recommendation of this group is first considered by its parent body, the Technical Advisory Council, and must be approved finally by the Association's Board of Direc-

tors before funds can be appropriated. Funds to support the program are solicited from all member companies of the entire Association, and some interested non-members also contribute. Thus it is a true industry-wide effort, not just that of a few companies.

As pointed out above, the over-all program was initiated in early 1954. At the outset, emphasis was placed by the member companies themselves on the development of analytical methods, and it wasn't until this phase was essentially complete that it seemed right to initiate basic research projects. Consequently, the outside research program did not start until early 1955. Since that time, however, and through June 1960, the Association has appropriated $275,000 for support of this work. This amount does not include significant additional expenditures absorbed by the member companies of the Research Steering Committee and various subcommittees in working together on such activities as analytical developments, investigating individual problems, attending meetings of professional societies, and similar activities.

The research program has been directed (*a*) to seeking answers to the various questions which were raised, and (*b*) to seeking means of alleviating what problems might exist. It is the purpose of this paper to briefly discuss this program and its findings to date.

Detergent Definitions

Because the chemistry of synthetic detergents is a specialized and complicated field, it is not surprising that there still is some confusion when discussing or reporting on these materials. Consequently, a simplified approach to defining detergents has been prepared, avoiding as far as possible precise chemical definitions and comparisons.

A detergent, by definition, is anything that cleanses. As such, ordinary soaps, the new "synthetic" detergents, plain water, even sand when used for scrubbing, can all be classified as detergents. Thus, in Figure 2, which shows a representation of the two major types of packaged household washing products which the housewife might purchase, both the new "synthetic" and the old "soap" products are labeled as "detergents," in order

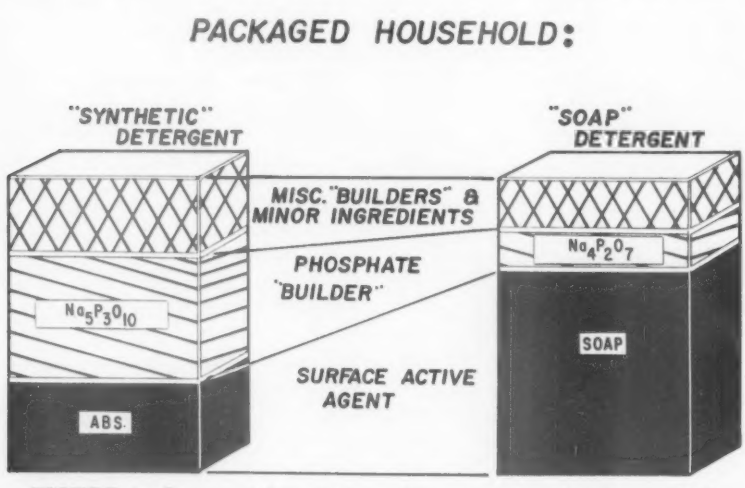

FIGURE 2.—Representation of two major types of packaged household washing products.

to help make the comparison more understandable.

Definite points of similarity between these two products are to be noted, in that the large proportion of each contains a surface active agent and a phosphate builder. Of course, the surface active agents, or surfactants, differ between the two, as will the exact chemical identity of the phosphates. Also, the proportions of each are obviously different. Nevertheless, in the broad sense, they both contain the same basic types of materials which, when properly formulated, combine to do equally good jobs of getting out dirt.

The surfactant portion of the packaged product is the organic agent which lowers surface tension, forms a "bridge" between soil and cloth, and makes suds. In the packaged household soap detergent it is called by the same name, "soap," a name applied to it for many centuries before chemists finally identified its specific chemical structure. Actually, it is the sodium or potassium salt of a high molecular weight fatty acid derived from a natural fat or oil. This surfactant material is the major part of the formulation. In some brands it may be 90 per cent of the product. Thus, it is not hard to understand and not unreasonable to refer to the surfactant part and the entire product by the same name.

In the packaged household synthetic detergent, however, the surfactant is a much smaller portion of the entire product than in the case of packaged soaps. Thus, to call the surfactant portion "detergent" can be very misleading. To be precise, it should be called just "surfactant" or "surface active agent" and the term "detergent," "synthetic detergent," or "syndet" should be reserved for the complete package product. When this is done the area of confusion, particularly in reporting and interpreting analytical data, is clarified. The specific surfactant material most widely used in household detergents is known as ABS (alkyl benzene sulfonate).

The phosphate builders present in both packaged household soaps and detergents are mildly alkaline complex phosphates which, because of their soil-suspending properties, help "build" the formulation into a product which will do the best (now known) job of getting dirt out of clothes. The specific phosphate compounds used in packaged soaps and detergents are really not very different.

One point of interest is the fact that the per capita consumption of packaged detergents and soaps has remained about the same during this period when detergents replaced soaps in the home. Total consumption has gone up only because of population increase. Actually, the total amount of surfactant material from synthetic detergents which goes "down the drain" today, as it were, is less than the total amount of surfactant material from soap products which went down the drain in 1947, because the percentage of surfactant in detergents is so much less.

As mentioned above, the specific surfactant material most widely used in household detergents is ABS, and this compound along with the complex phosphates, has been the subject of the Soap Association's research program. The first step taken by the Association was to study existing analytical procedures, and to attempt the development of improved ones.

Analytical Problems

When the early questions concerning detergents were raised, a study of existing analytical methods for ABS in the dilute concentrations found in rivers and wastewaters quickly showed that the methods lacked precision, and were susceptible to interferences. Consequently, after more than 20,000 manhours of effort, a method was developed for ABS based on infrared techniques

(3) which provided an exact identification of the ABS present. This unequivocal method is complicated, and not suitable for routine use. However, it has proved its value, for while in many cases shorter techniques are reasonably accurate, at times they are grossly inaccurate, and can lead to serious errors in interpretation. For example, one instance of record indicated that 1.5 mg/l ABS were present in a water sample analyzed by a colorimetric procedure, while in actuality there was no true ABS present, as measured by infrared.

Despite the shortcomings in the colorimetric methods, they can serve as very good screening tools. In the first place, since 1954 they have been much improved in precision. Further, since total interferences are positive, analytical results can be considered to show the maximum possible ABS present, and only when an unusually high level appears to be present is it necessary to check more closely by infrared for the true ABS level. This point of view is rather thoroughly discussed, and both the infrared method and an improved methylene blue colorimetric method are included, in a task group report (4). It is expected that these methods will be included in the next edition of "Standard Methods."

At the same time, it is recognized that even the best of the existing short colorimetric procedures are inadequate, and in hopes of developing a new one which will be quick, simple, and reliable, further work is being sponsored at the University of Southern California. New dye-solvent combinations are being sought which will give greater selectivity for ABS while simultaneously eliminating interfering materials, and several give hope for eventual success. This project was started in the late summer of 1957 and was estimated to last slightly more than two years.

In the area of phosphates, an analytical method (5) was developed for the quantitative differentiation of the various types of phosphates in surface waters. A subcommittee drawn from 12 industrial organizations spent over two years of cooperative effort in developing the new method, and it too is being considered for inclusion in the next edition of "Standard Methods."

Thus, with the analytical tools becoming available, it was felt that research projects could be undertaken, and the first of these began in 1955.

Sewage Treatment Problems

A great deal of effort has been spent by the Association in attempting to answer the various questions raised concerning the effects of ABS on sewage treatment. What happens to ABS in treatment? Does it have an adverse effect on sewage bacteria? How much is degraded in treatment? Does it cause frothing in activated sludge plants? These and other aspects were and are the subjects of investigations by the Massachusetts Institute of Technology, the University of California, the University of Wisconsin, and Rolf Eliassen Associates.

ABS Removal

One of the first projects, the results of which have been reported by McKinney and Symons (6), was on the fundamentals of the biological oxidation of ABS. This work firmly established that a major portion of the ABS entering the secondary activated sludge plant is degraded. This work also showed that ABS is not toxic to the bacteria.

Having established these points the direction of the project turned toward accomplishing maximum ABS removal in actual practice. Experiments in laboratory units, plus experience on related problems, indicated that maximum removal, in the order of 80 per cent, could be accomplished in a high-solids complete-mixing activated sludge system. The principle

of this treatment involves the introduction of the sewage into the aeration tank uniformly along the tank, rather than at the end. This provides more complete mixing, and consequently treatment, thus accomplishing greater breakdown of the ABS than in the conventional process. One of the apparent reasons for this is that high suspended solids content—in the range of 6,000 mg/l—can be maintained. As a bonus to the removal factor, it is possible that frothing can be better controlled under these conditions.

As a result of these studies and since existing plants could be modified, a full-scale study was developed at the City of Cranston, Rhode Island. This was under joint sponsorship of the Soap Association and the State of Rhode Island. The plant at Cranston has two parallel systems, where one could be converted to the new process while the other would serve as a control. So far the results have not fulfilled the promise of the laboratory findings, but it is still hoped that equivalent operation eventually can be achieved.

Other work on ABS removal by sewage treatment was reported by McGauhey and Klein (7). Both conventional and modified activated sludge systems were employed, and to avoid analytical discrepancies, radio-tagged isotopes of ABS were used. It was determined that in conventional treatment about 2 to 4 per cent of ABS is removed in primary settling, and that 50 per cent or more is removed by both primary and secondary treatment. These results on total ABS removal independently corroborated the findings on conventional treatment at the Massachusetts Institute of Technology. Other independent findings at California agreeing with MIT results are: (*a*) the improved over-all ABS removal obtained when suspended solids are in the 5,000 to 6,000 range, (*b*) the lack of detrimental effect on sewage treatment processes of existing concentrations of ABS, and (*c*) the lack of detrimental effect to bacteria by existing or even foreseeable ABS concentrations. In the latter consideration, the MIT work even gave indications that ABS might actually stimulate utilization of other organic material by some sewage bacteria.

From the fact-finding studies, the California investigators went on to attempt development of alternate or additional means by which ABS removal might be improved. The most interesting and promising approach in this direction has been the continuous removal of ABS by deliberately frothing the effluent from the activated sludge aeration tanks, followed by skimming off the froth and disposing of it separately. This approach takes advantage of the known tendency of surface active agents to concentrate in the froth. Total removals, when this step is added to the regular activated sludge treatment process, have ranged from 82 to 93 per cent of an initial concentration of 10 mg/l ABS in the raw sewage. The possibility of destroying the froth containing the ABS by burning it with digester gas is being studied.

Frothing

The subject of frothing has also been the interest of the University of Wisconsin, in a project to determine the causes of this problem in activated sludge aeration tanks. There has undoubtedly been an increase in frothing reports since the end of the war, and to a large extent they have seemed to parallel the increase in detergent usage as well as the increase in new treatment plant construction.

The work at Wisconsin as reported by Polkowski, Rohlich, and Simpson (8) has established that while ABS can contribute to foaming, many other factors, either alone or combined, are also involved. Low suspended solids concentrations appear to promote

frothing, while high solids reduce or eliminate it. This was observed and reported a number of years ago at San Antonio (9). Protein degradation products, present in almost every domestic sewage, can cause frothing. Temperatures above 70°F and high pH values are associated with frothing. Conditions during low flow periods, particularly at night when ABS levels in the influent are frequently low, also seem to be involved. And aeration rates certainly play a role in the problem.

At the present time, the Wisconsin studies utilize a rather unique laboratory-scale continuous-flow activated sludge plant in which statistical interpretation of the factors being tested is possible. The factors under investigation consist of high and low variations in suspended solids, detention time, aeration rate, ABS content, BOD of sewage, and nitrogen to BOD ratios.

Even so, it is clear that there will remain other factors in frothing which will not be understood. This is emphasized by the findings of a survey made two years in succession of the frothing conditions on the Wisconsin River at Wisconsin Dells, at which time various tests were made, such as frothing measurements, temperature, ABS concentrations, and nitrogen concentration. The first year no frothing occurred, possibly because spring runoff was light. The second year the survey started early in March. Little or no frothing occurred until about the middle of April, when the flow of water over the dam spillway increased. At this time almost a foot of froth built up below the dam, yet the ABS concentration never exceeded 0.03 mg/l. Organic nitrogen concentrations also were low, and apparently these materials did not contribute. Consequently, other factors, one of which may be air entrainment, must have been involved.

Thus, it appears that while a better understanding of the causes of frothing and means for controlling its production may be forthcoming, more remains to be learned.

Water Treatment Problems

In the area of water treatment, two projects have been supported by the Association, one at the University of Illinois and one at The Johns Hopkins University. The Illinois project was primarily concerned with the phosphate builder component of household detergents. Engelbrecht and Morgan (10) reported on these studies which were undertaken to: (*a*) survey typical surface streams in the State of Illinois for the amount and type of phosphate present, and (*b*) determine whether these concentrations might have any effect on conventional water treatment operations. This research stemmed from literature reports based on laboratory work that the complex phosphates used in detergents would, at relatively high concentrations, interfere with coagulation and settling.

The survey, using the improved phosphate procedures developed in the analytical research phase, showed that the phosphate concentrations in Illinois surface supplies were low, with complex phosphates generally less than 0.5 mg/l and the simple orthophosphate about the same. Of particular interest is the finding that almost half of the total phosphate present comes from the drainage of agricultural land.

Laboratory studies confirmed another point indicated by the stream survey—that the complex phosphates degrade to the simple ortho form in the presence of stream biota, the rates of degradation varying according to the physical, chemical, and biological conditions encountered.

The studies of the effect of the complex phosphates on coagulation and settling showed that while the 0.5 mg/l did exert a very slight interference, it could be overcome readily

by either a moderate increase in coagulant dosage or an increase in settling time.

Over-all, the results showed conclusively that phosphate levels found in Illinois waters have no practical significance on water treatment, and further that of the phosphates present in these streams, only a portion can be detergent-derived.

The Johns Hopkins project, reported by Renn and Barada (11), has been concerned with developing effective and economic means for removing trace quantities of ABS from water supplies, should this ever become desirable. Under normal circumstances, ABS levels in surface waters are so low that no tendency to foam exists; it is only in rare instances, almost all associated with low raw water supplies brought on by droughts, that ABS has been present in concentrations high enough to be noticeable. And of course, under these circumstances, there were other polluting materials present in much higher than normal concentrations.

Looking for physical means by which removal could be accomplished, a number of materials were evaluated which might serve as ABS adsorbing agents. These included garden soils, river silts, china clay, diatomite, silica gel, calcium carbonate, oil emulsions, paraffin, and activated carbon. Of all the materials tested, activated carbon appeared to be easily the most effective, while at the same time different varieties of carbon exhibited appreciable differences in their ability to adsorb and remove ABS. The results showed that, when using a carbon commonly employed by treatment plants (but not the most efficient from the viewpoint of ability to adsorb ABS) about 40 mg/l was required to remove 90 per cent of an original ABS concentration of 0.2 mg/l; while 95 mg/l was required to remove 90 per cent of 2.0-mg/l ABS. These carbon concentrations, while high in terms of normal usage, should not prove an excessive burden for short period application. Further, since higher ABS concentrations would be accompanied by higher levels of other materials, this carbon application should prove effective in simultaneously removing many of these.

Other Activities

In addition to the Association activities in connection with the basic research and analytical areas covered above, a good deal of effort is expended in cooperation with other groups concerned with various aspects of the detergent situation. For example, the Chemical Industry Committee advisory to the Ohio River Valley Water Sanitation Commission (ORSANCO) maintains a subcommittee which works on this problem, and the Association is represented in the membership of this subcommittee. Another organization with which the Association cooperates is the U. S. Public Health Service, formally through the National Technical Task Committee on Industrial Wastes, and informally through cooperation with the Taft Sanitary Engineering Center. A problem of mutual interest in which the Association is active is the general pollution of ground waters by septic tanks and cesspools. The Association also has membership on both the Task Group on Synthetic Detergents and the Analytical Task Group of the AWWA. Liaison is maintained with the American Society of Testing Materials, which has a task group concerned with analytical methods for detergents, and also with the British Government's "Standing Committee on Synthetic Detergents." In connection with the British situation, where pollution problems in general might be expected to be more severe than in this country because of a shorter water supply, it is interesting to note that the Second Progress Report of

their Committee, published in March 1959, states that reports of various difficulties attributed to synthetic detergents have been somewhat fewer during the past year than in the previous year, although some difficulties, apparently not serious, still persist (12).

Summary

The Soap Association research program is a varied and comprehensive one. More detailed reports on the findings of the various projects are available as shown in the reference list and more will be published in the future by the individual researchers.

This paper is intended to point up the sincere interest the Association has in this problem. As brought out before, all aspects of the sanitary engineering field are of tremendous importance to the public, and the Association hopes that the results of its research effort will not only solve any problems which might relate to detergents, but can also be projected to answering others of the tremendous complex of problems faced by this field today.

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CORRECTION

In the paper, "Aquatic Life Water Quality Criteria. Third Progress Report," by the Aquatic Life Advisory Committee of the Ohio River Valley Water Sanitation Commission (THIS JOURNAL, **32**, 1, 65; Jan. 1960), on page 69, in line 14 of the right-hand column, the word "can" should be "cannot." This should read ". . . complex cyanides cannot always be distinguished . . ."

Stream Pollution

GRAPHIC EXPRESSION OF BIOLOGICAL DATA IN WATER POLLUTION REPORTS

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Many present day water pollution problems require attention to the responses of organisms exposed to the changing aquatic environment and fall within the sphere of interest of biologists. Frequently, the organisms of concern are desirable ones, such as fish and shellfish, which often respond to the pollution environment by becoming less numerous and deteriorating in quality. Of concern, also, are undesirable organisms, such as bloom-producing algae and slime growths, which sometimes become so numerous as to be a nuisance. In either situation, the consequences are costly—in one case, loss of a valuable resource—in the other, an expensive problem of organism control. In spite of these and still other areas of legitimate interest, the voice of the biologist too frequently has been feeble and unclear. There no doubt are a variety of causes to account for this. A vitally important one is the frequent failure of communications between biologists and others who share their interest and enthusiasm for water conservation. That failure of communication and possible remedies for it form the subject matter of this paper in the hope that the valuable biological work in this field will yield a more useful product.

Biological information pertinent to water pollution surveys has little value or utility unless presented in a form that is readily visualized and understood. Except for the median tolerance limit (TL_m), generally expressing satisfactorily the result of toxicity tests typically using fish, biological data pertinent in some way or other to stream conditions are often poorly presented for appraisal by the public and by persons not specifically trained in biological sciences. Once the funds have been expended to gather biological data, it is only reasonable in the interest of assuring maximum usefulness that they be presented in some clearcut form and described as succinctly as possible. It would be beneficial if biotic reflections of water quality could be expressed in meaningful numbers susceptible to mathematical manipulation as are BOD and some other data, but limited efforts in this direction have not yet been wholly successful. Accordingly, while it is possible for biotic data to show seriousness of pollution and need for remedial measures, such data do not indicate appropriate capacity or design of remedial works, and are not intended to do so.

In the past, and unfortunately at present also, it is not uncommon to find the biologist's report held aloof from that of his colleagues who ad-

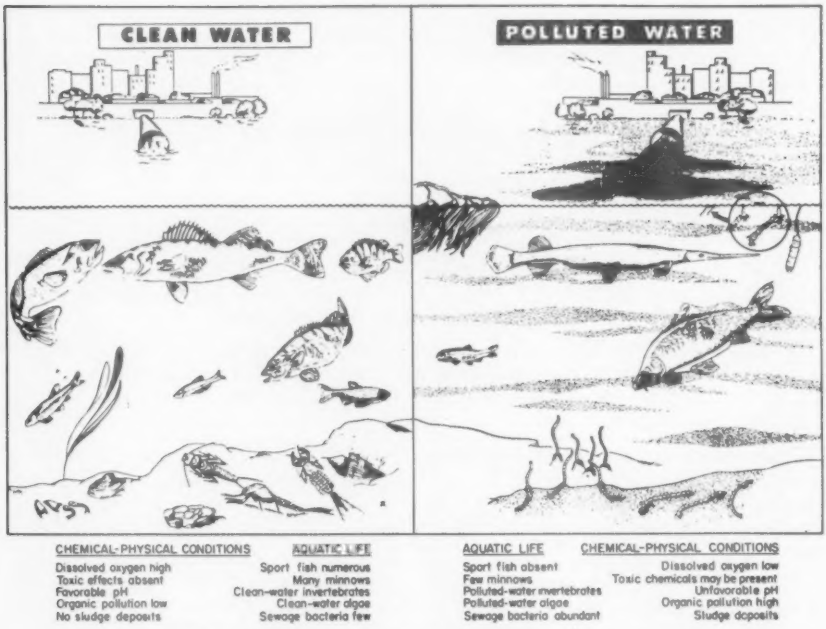


FIGURE 1.—Pictorial diagram showing water quality effects on aquatic life [after Ingram, Bartsch, and Jex (10)].

dressed themselves concurrently to chemical, bacteriological, and engineering aspects of the same problem. Traditionally it appeared as an appendix, gave long lists of technical names of organisms found, and described the complexities of stream biology, but failed to relate biology clearly to the other data or to the essence of the problem. No thinking person will deny the importance of recording the names of organisms that make up the spectrum of life in various environments affected by pollution. Such information adds to the general store of ecological knowledge and has interest from a number of points of view. But too often such lists appear as an end in themselves rather than a data-assembling step preliminary to problem analysis.

Whether or not justified, it undoubtedly was the apparent sanctity of this type of thing that caused Wylie (1) to write: "Scientists—and especially biologists, whose disciplines have benefited less often than some others from an extreme need to communicate with congressmen and even the electorate—have for generations been free to immolate themselves in proud palaces of nomenclature. Today, a herpetologist can converse with an entomologist about science only up to the level of pregraduate study. Beyond that, interpreters are as indispensable as uncommon. Yet, instead of being embrarrassed by their terminological entombment they take pride in the matter. For many, indeed, facility in the local language represents their only palpable achievement after decades of learning and labor." The admonition implied is simply this—in the interest of clarity and usefulness, please do not say "*Monolassiocolimino-*

phylocumhypophylum carpodendrum" when well-known "Joe" or "Bill" will do just as well.

Described in the following paragraphs are methods that have been used effectively to present biological data in water pollution survey reports. One or more of the following graphical expressions, together with pertinent interpretive schemes, make it possible to say "Joe" and "Bill" in a useful way to show important biological relationships. Graphical presentations that can be used effectively to summarize the impact of pollution on stream life include bar graphs, sector diagrams, simple line graphs, photographs, and pictorial diagrams. Some examples of publications especially pertinent to this discussion because they used graphics for effective expression of biological data and are readily available are those by Bartsch (2), Patrick (3), Henderson (4), Surber (5), Ingram (6), Beck (7), Wurtz (8), and Bartsch and Ingram (9).

Pictorial Diagrams

Pictorial diagrams such as Figures 1 and 2 * have a dual function in communicating biological knowledge effectively. In the clean-up campaign type of water pollution control leaflet or brochure intended for wide distribution to the public, they can be used to show the very general as well as some of the more specific impacts of pollution on living aquatic resources. They also function, and perhaps best, as expressive educational tools for public hearings and meetings, at civic club addresses, and in conservation and nature study courses in the colleges

* Figure 2 was modified from a figure in "Environment and Health." PHS Publication No. 84, Federal Security Agency, Public Health Service, Washington, D. C. (1951).

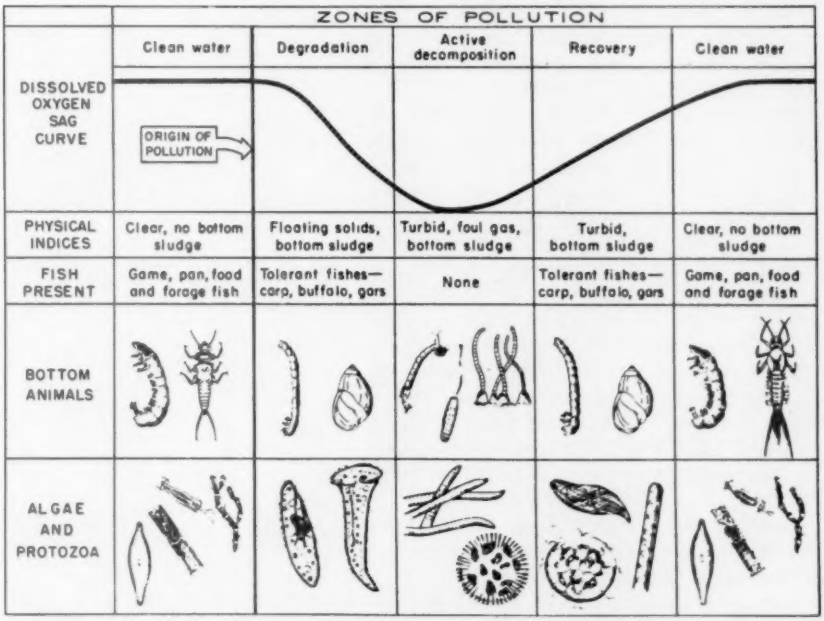
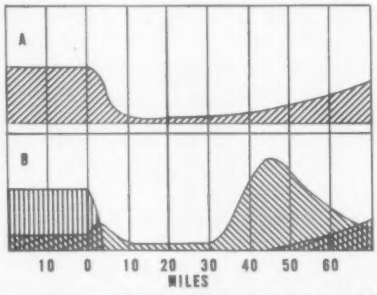


FIGURE 2.—Pictorial diagram showing some examples of life associated with clean water and water polluted by organic wastes.

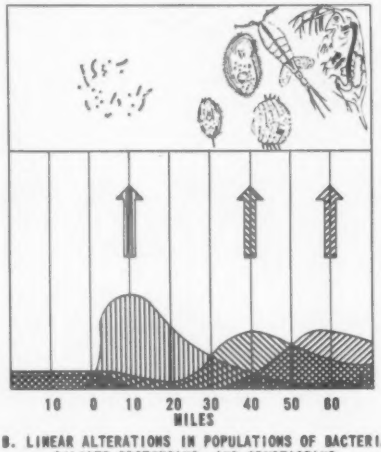
and other levels of education. Figure 1 was developed as a display poster to show, in dramatic fashion, the gross impact of pollution on aquatic life (10). Physical and chemical conditions are shown together with existing aquatic life influenced by them so that interrelations between living conditions and existing life are clearly evident. The poster suggests the kinds of contribution to be made by various sciences when they unite in a joint attack on the problem. This figure has been republished in a number of industrial and conservation journals to emphasize the potential effects of pollution on aquatic life. It was used by Hiram Walker and Sons, Inc. (11) to illustrate pollutional effects in the Illinois River, by conservation agencies of West Virginia (12), Wisconsin (13), and Tennessee (14), and by the Tennessee Department of Public Health (15).

Other pictorial diagrams have been used to illustrate biotic changes resulting from pollution which occur in linear fashion along a stream. In Figure 2, examples of specific characterestic aquatic organisms are shown in relation to stream condition expressed as familiar physical and chemical parameters indicative of heavy pollution by raw sewage. Notable are the dissolved oxygen sag curve and linear distribution of sewage sludge and solids which help to delineate the stream zones shown. This figure is essentially a qualitative one, showing for the fish a shift from desirable kinds to less desirable ones or none. For the bottom animals it shows a replacement of high oxygen demanding insect larvae, incapable of inhabiting sludge, by much less sensitive organisms, such as red "blood worms," sludge worms, rat-tail maggots, and sewage mosquito wrigglers. The algae and protozoa shown are the kinds that one would expect to find dominant in company with the indicated fish and invertebrates.

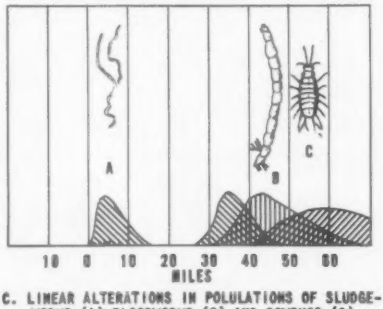
A quantitative dimension is added to the qualitative distribution of selected organisms in Figure 3. The point of entry of the pollution, which



A. RESPONSES OF BOTTOM ORGANISMS TO ENTRY OF RAW SEWAGE AT ZERO MILEAGE LEVEL. (A) VARIETY DISTRIBUTION: (B) POPULATION ALTERATIONS OF "CLEAN WATER" AND "POLLUTIONAL" BOTTOM FORMS



B. LINEAR ALTERATIONS IN POPULATIONS OF BACTERIA, CILIATE PROTOZOANS, AND CRUSTACEANS



C. LINEAR ALTERATIONS IN POLULATIONS OF SLUDGE-WORMS (A) BLOODWORMS (B) AND SOWBUGS (C)

FIGURE 3.—Pictorial graphs demonstrating effects of raw sewage on populations and kinds of selected organisms [after Bartsch (2)].

is raw domestic sewage, is designated as zero mile. Figure 3A shows clearly that the entry of pollution causes the variety of bottom organisms to diminish. At some reach downstream (between miles 40 and 50) there is a stimulation of tremendous numbers of one or two species. Figures 3B and 3C show the linear order of dominance of selected organisms.

Photographs of Organism Samples

Where one is interested in the influence of wastes on the bottom productivity of fish-food organisms, photographs of the collected samples are a simple but highly effective mode of data expression. Without verbal embellishment the essentials of the situation in the stream are evident at a glance. This method was used to advantage by Henderson (4) to show conditions in the South Fork of the Shenandoah River, Virginia, downstream from industries discharging chemical wastes. Results of a later clean-up campaign on the same river can be well shown in this way, also (Figure 4).

Bar Graphs

Simple bar graphs can be used advantageously in summarizing biotic data to accompany graphic expressions of chemical and physical data. Unlike line graphs, they do not tend to create a false impression that biotic abundance follows a smooth ascending or descending pattern between stations simply because the points are con-

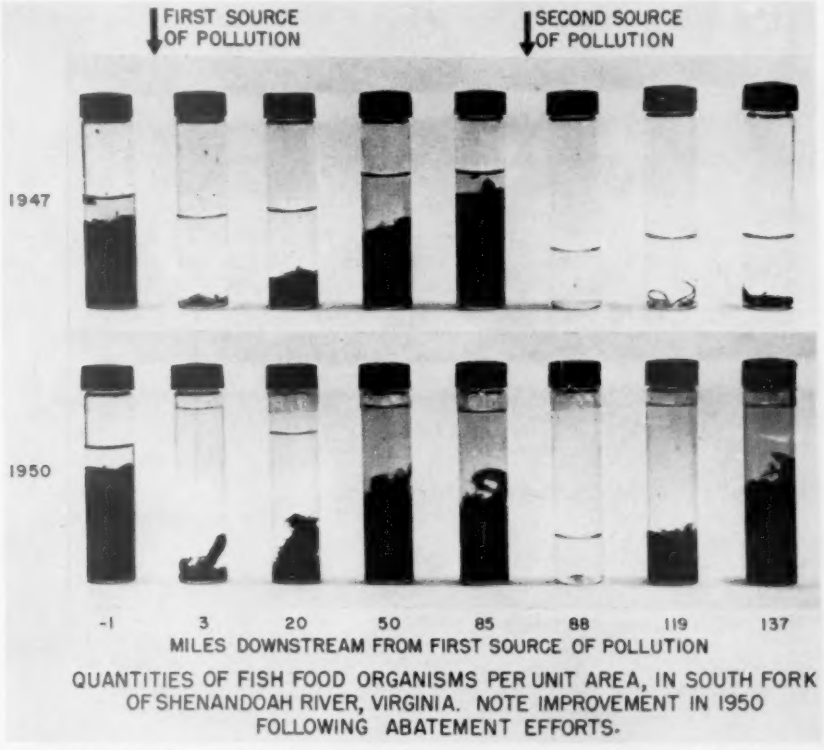


FIGURE 4.—Photographs of collected samples, showing quantities of fish food organisms per unit area, in South Fork of Shenandoah River, Va. Comparison of two years shows improvements following abatement efforts [after Henderson (4)].

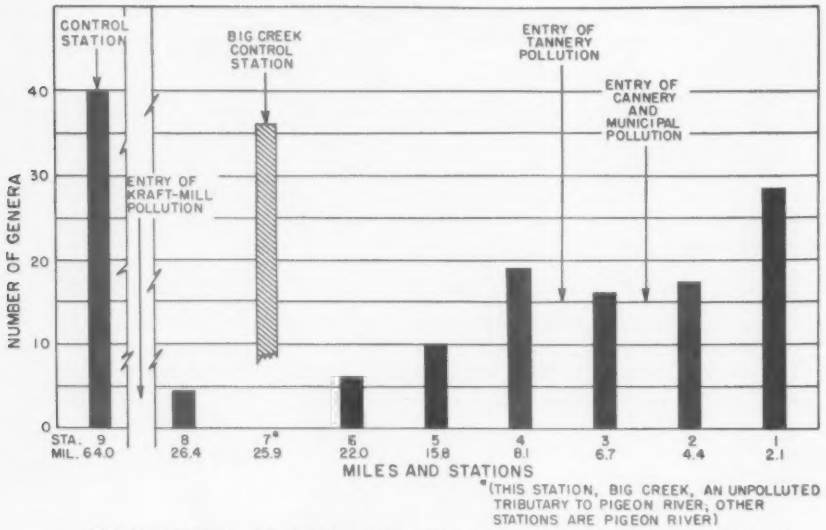


FIGURE 5.—Vertical bar graph showing total genera of organisms, exclusive of fish, collected in Pigeon River and Big Creek, Sept. 1953 [after Mullican, unpublished].

nected by straight lines. Spacing of bars can be so arranged that pertinent watercourse data, such as location of pollution sources or tributaries, can be clearly shown (Figure 5). This figure summarizes simply and concisely seven pages of tabular data dealing with generic names of the organisms found at each of nine stations along 61.9 miles of stream. Station 9 is a control station in a river reach above major sources of municipal and industrial pollution. Station 7*, another control reach is on an unpolluted tributary that joins the Pigeon River between sampling points where maximal depressing effects of pollution on the variety of aquatic life are evident.

Horizontal bar graphs have been used less commonly than the vertical type in stream pollution work. In Figure 6 data, which otherwise would form a series of lengthy tables of the type often hidden in a report appendix, are presented in an interpretive and revealing way. Actually, this chart demonstrates how three parts of a biotic picture can be presented together in a meaningful form where, if done separately, interrelation between organisms, pollution, and waste discharge history would be much less apparent.

Collections of aquatic life on which Figure 6 is based were made in July and September 1952. The July collections were made after the great bulk of industrial production was curtailed by a steel strike along the Mahoning River, Ohio, and while the load of remaining pollution came from untreated municipal sewage. September collections were made at the same stations after the strike was settled and industrial production was resumed. Then the pollution load consisted of both industrial and municipal wastes. Differences in the number of genera of plants and animals under conditions existing in July and September are shown in the right-hand part of the chart. Stations 1 and 2 were control

reaches; all other stations were subjected to varying loads of pollution. The left-hand side of the chart shows the per cent reduction of genera in September over July 1952. It is obvious at a glance that the biotic variety of the river was reduced concurrently with resumption of industrial activity and the resulting increased pollution loads reaching the stream. That the indicated reduction is not attributable to seasonal variation of aquatic life is attested by the similarities in generic numbers collected at upstream Control Stations 1 and 2 in both July and September.

Figure 7 demonstrates the use of vertical bar graphs, superimposed over a map of an area, to pinpoint spatially the variation in bottom organisms per square foot of area sampled. This graphic example makes it possible to visualize the influence of settleable solids from a glass sand operation in limiting both the number of kinds and the quantity of individuals of bottom organisms. The wastes are carried down a small creek and enter the river on the south bank between Stations 1 and 2. Stations 1 and 1′ represent upstream control stations. The south half of the stream is the area principally affected by the waste. Bottom organisms are absent at Station 2, and only one was collected at Station 3. A slight increase in kinds and numbers of individuals was noted at Station 4. The stations in the north half of the stream show contrasting abundance of bottom organisms at Stations 1′ to 4′ which are outside the influence of the glass sand waste.

Patrick (3) has used vertical bar graphs to show the presence and variation in abundance of selected species of organisms as related to varying degrees of pollution. Bacteria, fungi, and aquatic flowering plants are omitted from the graphs. When the biotic data are so recorded, ". . . these histograms seem to fall into four general groups which we have designated

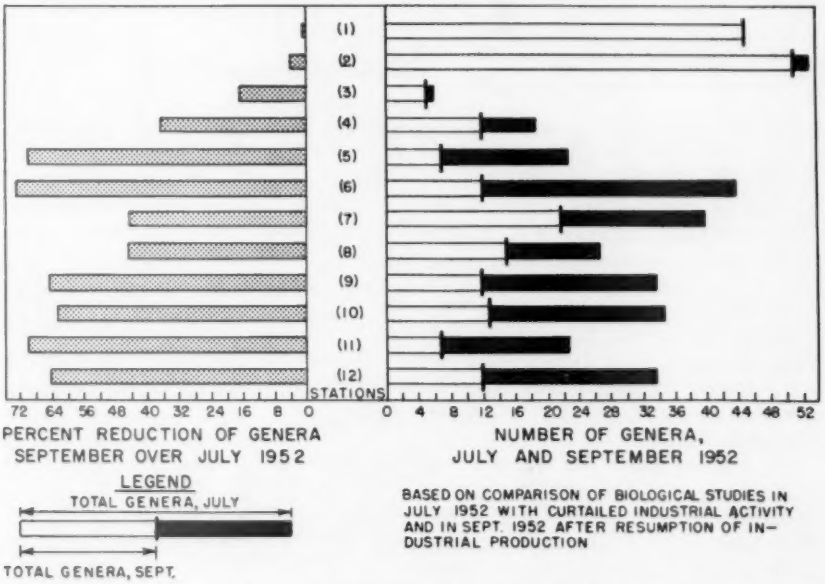


FIGURE 6.—Horizontal bar graph showing effect of industrial wastes on total genera of organisms in Mahoning River [after Ingram (6)].

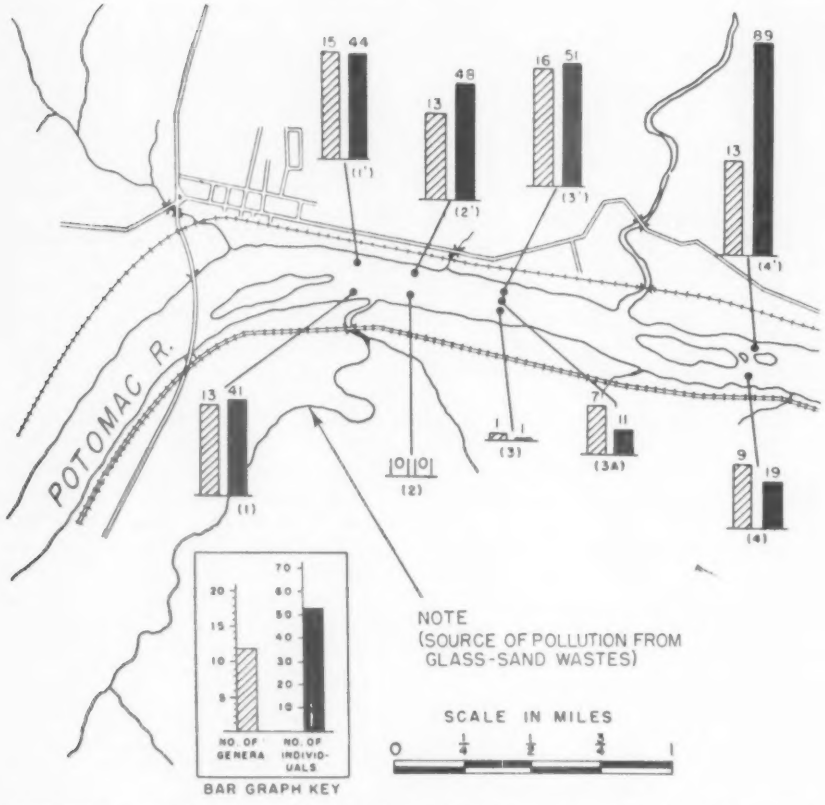


FIGURE 7.—Vertical bar graphs, superimposed over a map, used to show total genera and individuals of bottom animals per unit area [after Bartsch (16)].

as healthy, semi-healthy, polluted, and very polluted" (Figure 8). Species of organisms that are associated in any one of the seven columns of a histogram have been grouped together "Because certain groups behaved similarly in response to a given environment..." (3). These "groups" that form the columns labeled I to VII are characterized in Table I.

On the ordinate, the 100-per cent value represents the average number of species for each group found at stations characterized as ". . . typically healthy stations" on the basis of chemical, bacteriological, and biological data. The specific bases for interpret-

TABLE I.—Classification of Groups of Organisms Shown in Figure 8

Group	Organism
I	Blue-green algae; green algae of the genera *Stigeoclonium*, *Spirogyra*, and *Tribonema;* the bdelloid rotifers plus *Cephalodella megalocephala* and *Proales decipiens*
II	Oligochaetes, leeches, and pulmonate snails
III	Protozoa
IV	Diatoms, red algae, and "most of the green algae"
V	All rotifers not included in Group I, clams, gill-breathing snails, and tricladid flatworms
VI	All insects and crustacea
VII	All fish

ing the histograms to indicate whether they portray healthy, semi-healthy, polluted, or very polluted conditions (Figure 8) are:

1. Healthy Station: Groups IV, VI, and VII are all above the 50-per cent level. Groups I and II ". . . varying greatly depending on the ecological conditions and degree of enrichment of a stream."

2. Semi-healthy Station: (*a*) Either or both Group VI or VII are below 50 per cent and Group I or II is under 100 per cent, or (*b*) Either Group VI or VII is below 50 per cent, and Groups I, II, and IV, are 100 per cent or over; or Groups I and II are 100 per cent or over and Group IV is double width. The double width of columns is explained as follows: "'Semi-healthy' is the common condition in which the balance of life as described for a healthy station has been somewhat disrupted but not destroyed. Often a given species will be represented by a great number of individuals. This condition is noted in the histograms by a double width column."

3. Polluted Station: (*a*) Either or both of Groups VI and VII are absent, and Groups I and II are 50 per cent or greater. (*b*) Groups VI and VII are both present and below 50 per cent in which case Groups I and II must be 100 per cent or more.

4. Very Polluted Station: (*a*) Group IV is below 50 per cent and Groups VI and VII are absent, or (*b*) Groups VI or VII are present and I or II are less than 50 per cent.

Wurtz (8) presents histograms (Figure 9), which deal with selected or-

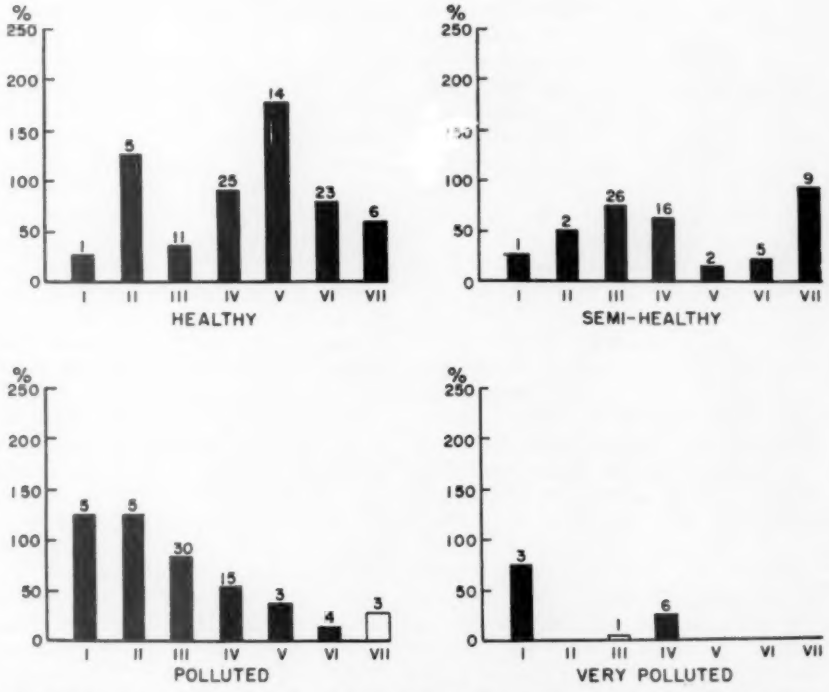


FIGURE 8.—Histograms, based on selected organisms, illustrating healthy, semi-healthy, polluted, and very polluted stations in Conestoga Basin, Pa. [after Patrick (3)].

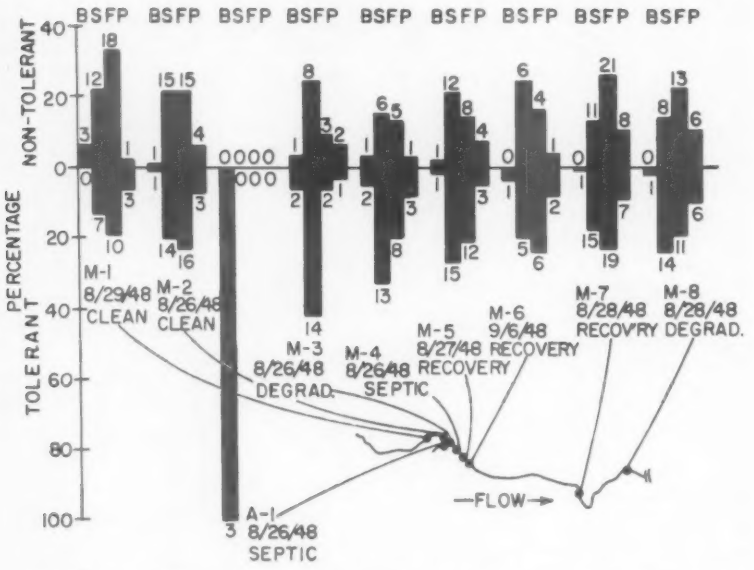


FIGURE 9.—Histograms, based on selected organisms, illustrating stream reaches of clean, degradation, septic, and recovery conditions [after Wurtz (8)].

ganisms that are "tolerant" and "non-tolerant" of pollution. "Tolerant" and "non-tolerant" organisms are not listed by scientific names but are shown by their relative abundance. Ranges of pollution intensity reflected in the graphs are not defined.

Each histogram is constructed of four columns, each representing one of the following categories: (*a*) B: burrowing organisms, (*b*) S: sessile organisms, (*c*) F: foraging organisms, and (*d*) P: pelagic organisms. Protozoa, non-tricladid turbellara, aschelminthes, and entomostracan crustacea are omitted from the histograms. Columns may extend up and down from a baseline. The "non-tolerant" portion of the population is plotted above this line and the "tolerant" portion below it. Wurtz (8) states, "The columns are plotted as a frequency index in which the total number of species found at any station represents a frequency of 100 per cent for that station. Thus the contained area in all the columns of any one histogram equals 100 per cent." He further states that, "In general, the stream may be considered as a clean-water stream when the non-tolerant species represent more than 50 per cent of the population. If the non-tolerant species drop much below this level there is cause for concern as regards stream conditions. The factor that causes this depression can be interpreted as pollution."

For the "normal clean-water station" the four columns making up a histogram, from left to right, would be "approximately" 5, 40, 45, and 10 per cent. These percentages that are stated to exist for a "normal clean-water station," are qualified by station: "However, this is considerably modified by environmental conditions as well as by the effects of pollution. Nevertheless, the proper interpretation of the relative species diversity in each

column is the most sensitive method of evaluating stream conditions. Unless gross differences exist between the total number of species at any one station compared with any other station, this feature cannot be used for the interpretation of pollution. It may, however, be considered as supporting evidence for the conclusions drawn as regards any particular station." Wurtz (8) states that clean stations had from 53 to 115 species and polluted stations varied in species from 3 to 46; species in the zones of recovery varied from 25 to 75.

Sector Diagrams

Sector diagrams have long been used to express biological conditions in polluted water. A paper by Surber (5) is a recent example in which such diagrams are used to show the abundance of bottom animals that he groups as clean-water, facultative, and pollu-

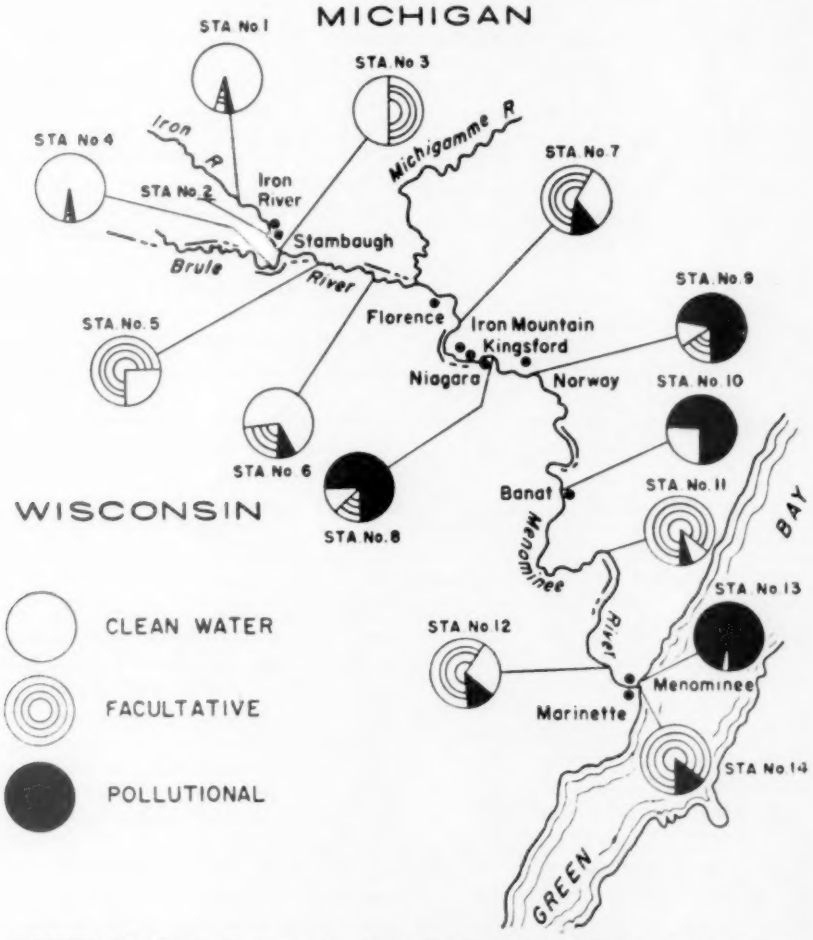


FIGURE 10.—Sector diagrams showing percentages of clean water, facultative, and pollutional bottom organisms [after Surber (5)].

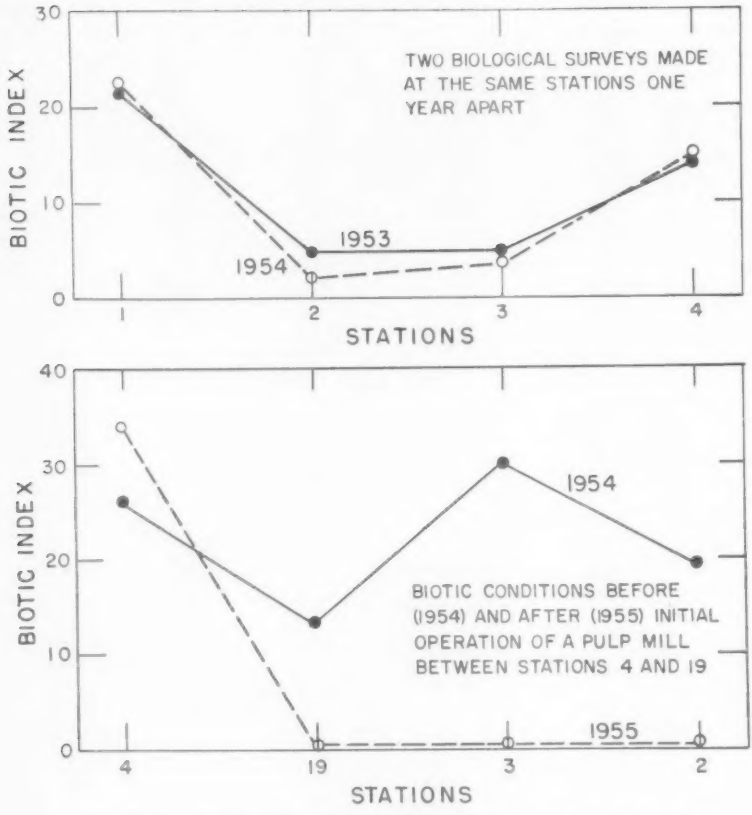


FIGURE 11.—Presentation of biological data expressed as biotic index [after Beck (7)].

tional, in studies of the Menominee and Kalamazoo Rivers, Michigan (Figure 10). He states that probably, ". . . only the use of 'facultative' requires explanation: facultative animals are those forms that are able to live in fairly heavily-polluted areas as well as in clean-water situations." This interpretation has not always been used; some workers, unfortunately, have lumped in this category organisms whose responses to pollution are not known. In addition, it is not always clear whether the categories refer to the total number of species or to total population.

Line Graphs

The line graph, of course, has been the common base for graphical presentation of most data found in reports of water pollution surveys. Too often, no attempt is made to project the significance of long lists of animal and plant names into interpretative graphs that are meaningful to those not familiar with scientific biological names. Through this simple device, however, one can avoid such long lists of names which for apparent lack of meaning are usually entombed in an appendix of the report. Simple line graphs when used where appropriate in place

of or to supplement name lists, can prove to be most useful to all who find need to read water pollution survey reports. Such enhancement of bacteriological, chemical, and physical data often could prove to be the yeast that leavens the bread.

In a recent paper, Beck (7) uses simple line graphs to demonstrate the usefulness of a new method for reporting biotic data. This method is one of the few attempts to express biotic condition as a single number. The number, called the "Biotic Index," is derived in two steps:

1. For a given stream station, determine the number of species of organisms that tolerate no appreciable organic pollution (Class I), and the number of species that tolerate moderate organic pollution but cannot exist under near-anaerobic conditions (Class II).

2. Biotic Index = $2(n$ Class I) + (n Class II).

This Biotic Index may be defined as "... an index value based on biological findings and indicative of the cleanliness (with regard to organic pollution) of a portion of a stream or lake." The index may vary from 0 to 40; the index that may be accepted without explanation as indicative of a clean stream is 10; a grossly polluted stream will have an index of 0; and a moderately polluted stream, 1 to 6.

The clarity with which a graphic plot of biotic indices expresses stream condition is shown in Figure 11.

Acknowledgment

Appreciation is expressed to the following persons who supplied data for incorporation into this paper: Mr. William M. Beck, Jr., Biologist, Florida State Board of Health; Mr. Harold Mullican, Chief Biologist, Tennessee Stream Pollution Control; Dr. Ruth Patrick, Curator of Limnology, The Academy of Natural Sciences of Philadelphia; Mr. Eugene W. Surber, Assistant Federal Aid Supervisor, Region IV, U. S. Fish and Wildlife Service, Atlanta, Georgia; Dr. Charles B. Wurtz, Consulting Biologist, Philadelphia, Pennsylvania; and Mr. Croswell Henderson, Water Supply and Water Pollution Research, Robert A. Taft Sanitary Engineering Center of the U. S. Public Health Service.

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MEETINGS OF INTEREST

Mar. 16–18	**Twenty-Third Annual Short Course for Superintendents and Operators of Water and Sewerage Systems,** Louisiana State University, Baton Rouge. Dean Fred H. Fenn, College of Engineering, Louisiana State University, Baton Rouge.
Mar. 29–30	**Second Joint Conference on Gaseous and Liquid Waste Problems,** Hotel Traymore, Atlantic City, N. J. Mid-Atlantic States Section of the Air Pollution Control Assn. and Industrial Wastes Assn.
Apr. 3–8	**6th Nuclear Engineering and Science Conf., 8th International Atomic Energy in Industry Conf., 6th International Atomic Exposition,** New York Coliseum, New York. D. P. Reynolds, c/o Engineers Joint Council, 29 West 39th Street, New York 18.
Apr. 4–8	**Course on River Pollution, Sewage Disposal, and Trade Waste Treatment,** University of Birmingham, Edgbaston, Birmingham, England. R. F. Wills, Civil Engineering Dept., The University, Edgbaston, Birmingham 15, England.
Apr. 5–14	**137th Meeting of the American Chemical Society,** Hotel Netherland-Hilton, Cleveland, Ohio. American Chemical Society, 1155 16th Street, Washington 6, D. C.
Apr. 7–8	**Ninth Annual Muncipal and Industrial Wastes Conference,** North Carolina State College, Raleigh. Division of College Extension, P. O. Box 5125, State College Station, Raleigh, N. C.
Apr. 20–22	**Third Biological Waste Treatment Conference,** Manhattan College, Riverdale, N. Y. Professor W. W. Eckenfelder, Manhattan College, New York 71.
Apr. 27–29	**Conference on Algae and Metropolitan Wastes,** Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio. A. F. Bartsch, Asst. Chief for Special Technical Services, Water Supply and Water Pollution Research, R. A. Taft Sanitary Engineering Center, Cincinnati, Ohio.
May 3–5	**Purdue Industrial Waste Conference,** Purdue University, Lafayette, Ind. Professor Don E. Bloodgood, School of Civil Engineering, Purdue University.
May 6	**Eighth Annual Pennsylvania Clean Streams Conference,** Penn-Harris Hotel, Harrisburg, Pa. R. V. Wall, Pennsylvania State Chamber of Commerce, State Chamber Building, Harrisburg, Pa.

THE OPERATOR'S CORNER

OPERATION AND MAINTENANCE OF GAS ENGINES AT SANTA ROSA *

By Murray B. McKinnie

Sewerage Works Superintendent, Santa Rosa, Calif.

The sewage treatment plant which serves Santa Rosa's 30,000 residents is located on a stream offering no summertime dilution. The plant was designed for complete treatment of 5 mgd using preaeration, sedimentation, trickling filters with recirculation, secondary sedimentation, and ponding. Figure 1 is an aerial view of the plant; Figure 2 is a flow diagram.

As can be seen from the flow diagram, there is no pumping of sewage until after primary settling. During the design of the plant, the consultants made extensive analyses of the costs

* Presented at the 32nd Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Dallas, Tex.; Oct. 12–15, 1959.

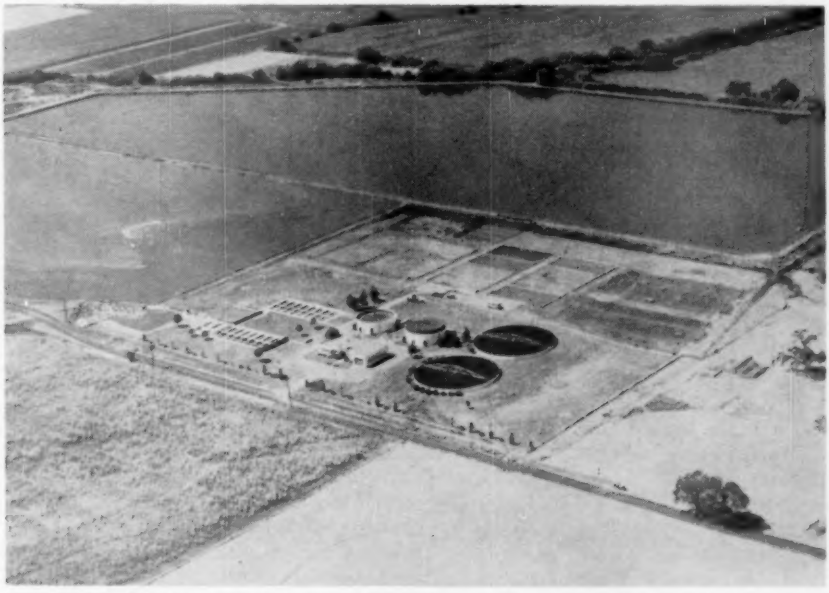

FIGURE 1.—Aerial view of Santa Rosa's sewage treatment works.

of pumping, both by electric motors and gas engines, and it was found that gas engines would be the most economical.

This analysis also showed that it would be sound economically to operate the gas engines to (*a*) pump sewage and (*b*) produce air for the preaeration system and the operation of the sludge air lifts. It would be necessary because of the size of the plant and the probable gas production to have standby electric power; this would make the use of engines for generation of power uneconomical. The engines were sized to pump a maximum flow of 18 mgd at a head of 18.5 ft and to produce, with the same engine, a maximum of 800 cfm of air @ 7 psi.

The preaeration system also was to be used for grit removal, and it was felt that there would be sufficient air produced for its proper operation at all engine speeds. Meeting this condition would permit flexible operation, since the engine speed could be set for a recirculation ratio of 1:1, regardless of the rate of incoming sewage flow.

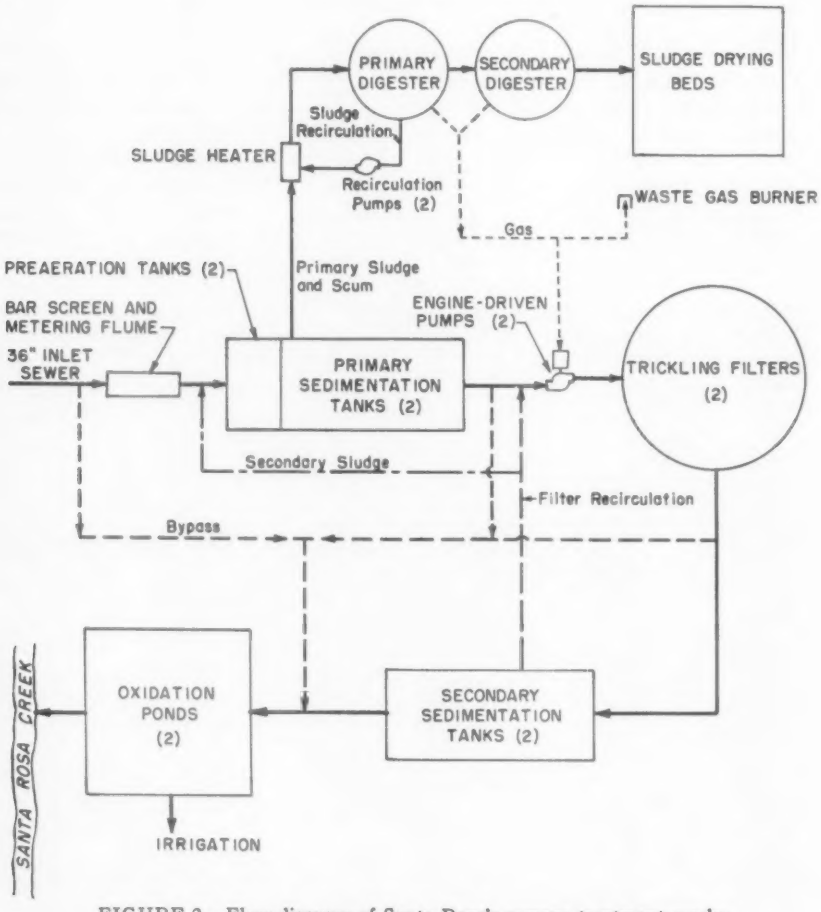

FIGURE 2.—Flow diagram of Santa Rosa's sewage treatment works.

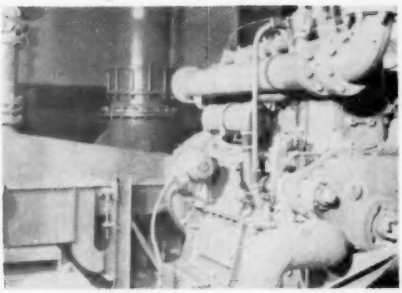

FIGURE 3.—Gas engine.

Description of Equipment

Two gas engines * are used at Santa Rosa (Figure 3), both are spark-ignited and operate on either sewage gas or liquid petroleum gas (LPG). They are started by 440-v electric motors which means that during a power failure it is not possible to start an engine.

The carburetion system consists of two Ensign regulators, one a Type S propane regulator which reduces the high pressure LPG to approximately the same pressure as the sewage gas. As long as there is sufficient sewage gas pressure, however, this LPG regulator does not function. The other regulator, a Type B, controls the sewage gas. Both regulators feed an Ensign gas carburetor.

Instead of using a radiator, the engine cooling system makes use of the sludge heat exchanger. The water in the engine jacket is pumped through it to dissipate the heat. Primary sludge circulating through coils is heated, and a gravity flow of sewage through other coils helps reduce the water temperature. This latter flow can be regulated to maintain the sludge at an even heat and still keep the engine water-jacket temperatures down.

The heat-exchanger mufflers, which help maintain the water temperatures, can be cut off so that as warm weather comes on the sludge temperature does not rise excessively. The water-jacket temperatures are maintained between 180 and 190°F.

Each engine, through a clutch system, drives a 20-in. pump and, by a V-belt, an air blower. The pumps were designed to pump 8,000 gpm @ 850 rpm and 12,500 gpm @ 1,100 rpm, which is the maximum running speed of the gas engines. After the plant was put in operation it was found that the pumps delivered more than the design quantities so that at maximum plant capacity it is not necessary to run the engines at their top speed. This added capacity also allows the engine to be run at far slower speeds and yet maintain a 1 : 1 recirculation ratio. The pumps discharge primary effluent to a high level sump which feeds two trickling filters. The flow to each filter is metered through an orifice meter.

The air system consists of an air filter which feeds the air blowers. The discharge from the blowers is metered and it varies with the engine speed. Judging from the conditions of the preaeration tank, the grit removal system works properly at all air capacities. Air production, since the plant started operation, has varied from a monthly average low of 360 cfm to a high of 650 cfm with the seven-year average being 505 cfm @ 7 psi. It was seven years before the pressure loss in the filter was sufficient to warrant a change of the filtering material.

Engine Operation

Startup

The engines did not just start and run without any difficulties. During the plant startup it was noted that to pump any appreciable amount of sewage, the engines had to run at high speeds. Even at that a 1:1 recirculation ratio could not be maintained. As the engines were operating on expensive LPG, it is easily understood why this was worrisome. It

* Waukesha 6 WAK.

wasn't until a factory representative arrived that it was found that the impellers were installed backwards. After the pumps were rebuilt and reassembled, the speed of the engines was lowered.

During the first months of the operation, the oil supplier made tests after various operating times and found that because of lack of dilution, the viscosity changed from the original grade of SAE 30 to SAE 40. It was found, however, that the oil maintained this higher viscosity for some time, and the engines could be operated for two weeks without undue thickening.

Early performances showed that the engines could be run much more slowly than planned because of the lower flow and overdesign of the pumps. This was lucky because expensive LPG had to be used until the digesters started to produce burnable gas. Even after gas was produced, the amount was not sufficient to operate the engines at high speed. Actually, things went along very well until the heavy rains came. Then it was found that the infiltration to the sewers was greater than anticipated. This high flow flooded the plant and the sludge sump, thus interrupting digester feeding for some time.

It is necessary to block the sludge sump when the flow to the plant reaches 12 mgd because the scum skimmers discharge into a trough that also goes to the sludge sump. As might be expected, gas production dropped when pumping stopped, and it was necessary to use LPG.

After sludge pumping was resumed, gas production increased. This increase, though, was almost too much for the waste gas burner to handle.

Following this upset came the heaviest blow of all. For no apparent reason gas production dropped and the primary sedimentation tanks went septic—one of the operators forgot to close a valve after transferring sludge, and digesting sludge was pumped into the plant drainage system and thence to the primary sedimentation tanks. The amount of sludge has been estimated as being from 5,000 to 15,000 gal. Inasmuch as the lowest plant flows were being experienced at the time, it took some time to get back to proper operation. This has been a contributing reason for the use of LPG since the plant started.

Spark Plugs

After less than a week of operation, it was found that the spark plugs were not standing up and had to be regapped. Every type available locally was tried; some lasted two weeks and others only a few days. The engine manufacturer then asked that still another type of plug be tried. This one had a heavy center metal core with three points so that as one portion burns away another takes over. This solved the problem of spark plugs and there is now no difficulty between engine checks.

Magneto

Solution of the spark plug problem led immediately to another problem, the magneto. It was always a question whether the magneto would last 600 hr without the replacement of points and condenser. Again a suggestion by the manufacturer solved this problem; by use of platinum points the magneto now runs for 3,000 hr without attention.

By this time it might be gathered that there was nothing but trouble with the engines. Actually, there was week after week of uninterrupted operation.

Regulators

One item that was a bit bothersome but not really a difficulty was the changeover from sewage gas to LPG. It was necessary to cut off the LPG as soon as the sewage gas was switched on because the sewage gas

pressure was low and the Type S regulators allowed LPG to still feed into the system. This little problem was caused partly by (*a*) the regulator being subjected to high heat and (*b*) the low pressure of the sewage gas, rather than an inherent defect of the equipment.

The regulators are water cooled and because the water is not of the best quality, diaphragms eventually deteriorate. Since there are long periods when LPG is not used there is seldom a sudden loss of sewage gas. The regulators are drained of water and LPG when not in use. With this method of operation it takes only a few minutes to start the LPG operation.

Major Trouble

The first major trouble started when oil consumption increased in engine No. 1. The consumption continued to increase and it was felt that something was radically wrong. Knowing that the valves had been ground after 3,460 hr of operation and again at 7,348 hr, it was decided to check the engine. This checkup was followed by a complete overhaul which was undertaken after 14,176 hr. It was performed by the manufacturer's serviceman and one of the mechanics from the city shop.

While the engine was torn down, a careful inspection was made to determine just what had happened. All parts were checked against factory specifications and showed very little wear. The cam-shaft lifters were in bad shape and this caused damage to the cam lobes. Consequently, the lifters and the cam shaft were replaced. Figure 4 is shown to give some idea of the condition of the engine block at the time of overhaul; Figure 5 shows one of the heads.

Valve oilers were installed to see if this would help cut down the frequency of valve grinding, but because of carbon particles in the oil, the oilers had to be removed. The carbon particles appear to have been caused by high heat.

Four thousand hours after the overhaul, the engine was running roughly, and no adjustment helped. It was found that the oil used for breakin purposes had carbonized, and that the head gaskets were leaking badly. The rough running and fluctuating oil

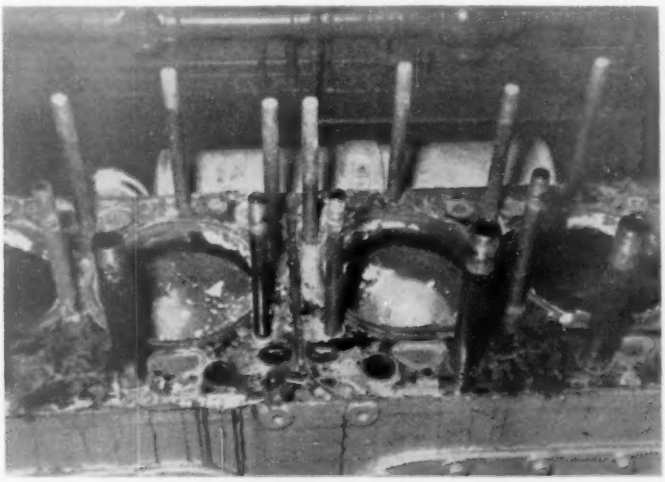

FIGURE 4.—Engine block at time of overhaul.

FIGURE 5.—Engine head at time of overhaul.

pressure prompted another overhaul, and this time one cylinder liner was replaced. Since the second overhaul, valves have been ground four times at from 2,000- to 4,500-hr intervals. Valve damage seems to be caused by dry gas, a high exhaust temperature, and a lean mixture of the air and fuel. The stack temperatures are well over 1,000°F, and the air-fuel ratio runs 16 or 17 to 1. Attempts to adjust the air-fuel ratio have been unsuccessful. The assumption that the high temperatures cause trouble may not be valid as engine No. 2 had its valves ground first at 1,579 hr, but the second time it was at 23,561 hr when the engine was overhauled. The engine was overhauled again at 28,969 hr.

Engine No. 1 has, at all times, given the most trouble. The heads have been planed and various dopes have been used, but the gaskets still leak. Within the last six months, however, an entirely new type of head gasket has been used for which there are high hopes.

Cost of Operation

The two questions asked most frequently are "What Does It Cost to Run the Gas Engines?" and "How Does this Compare with Other Fuels?" In answering these questions, the following cost items were taken into consideration: LPG, valve oil, crankcase oil, labor and transportation, and parts. As might be expected, costs vary from month to month depending on the repairs and the hours of operation.

Labor costs include the services of the plant maintenance man, city mechanics, and outside labor. They do not include the operator's time. For the period April 1952 to June 1959, the cost of operating engine No. 1 was $13,133.17; thirty per cent was for LPG, 0.9 per cent for valve oil, 11.2 per cent for crankcase oil, 32.4 per cent for labor, and 25.5 per cent for parts. This engine operated 29,812 hr at a cost of 44¢/hr. The engine ran on LPG 9.4 per cent of the time.

With engine No. 2 it is a different story. During the same period the cost of operation was $8,598.89, of which 46.4 per cent was for LPG, 1.9 per cent valve oil, 13.7 per cent for crankcase oil, 16.1 per cent for labor, and 21.9 per cent for parts. This engine ran 32,941 hr at a cost of 26¢/hr.

It ran on LPG 10.0 per cent of the time.

These costs are summarized in Table I which shows the cost per year for each item as well as the hours of engine operation. It should be noted that the LPG was the largest single cost item, yet this gas was used only 9.7 per cent of the time.

The labor costs do not include the operator's time to inspect the engines, take readings, wipe up, start and stop, or add oil. Three-shift operation is in force at Santa Rosa, with one operator per shift. A log covering several months' operation shows that an average of 28.8 operator man-hours per month is devoted to engine operation. This can be converted to an average monthly cost of $62.50 or 9¢/engine-hr.

Another item not shown is the depreciation or replacement cost of the engine and clutch system. If a 15-yr engine life is used, the depreciation cost is 7.2¢/hr. To bring all the costs together, Table II was prepared. Here, hourly costs for each year of operation are shown. To show the capital outlay funds used for the first overhaul of engine No. 1, the sum of 10¢/hr has been added to the costs from the start of operation until July 1955, and 36¢/hr has been added to the months from August 1955 to September 1956 for the second overhaul. To each monthly figure is added the operator-time cost of 9¢/hr and the depreciation cost of 7¢. There was no capital outlay cost for the overhaul of engine No. 2; this overhaul was done as a maintenance project out of regular funds.

TABLE I.—Summary of Operating Costs

(*a*) ENGINE NO. 1

Date	Propane	Valve Oil	Crank Oil	Labor, Trans.	Parts	Total
4/52–6/52	$1,425.31	—	$ 26.31	—	—	$ 1,451.62
7/52–6/53	176.93	$ 8.96	95.23	$ 75.94	$ 57.14	414.20
7/53–6/54	1,878.93	28.13	110.28	49.60	94.56	2,161.50
7/54–6/55	201.10	32.33	122.01	106.32	98.10	559.86
7/55–6/56	32.57	35.24	304.46	311.73	335.55	1,019.55
Capital outlay	—	—	—	514.59	876.71	1,391.30
7/56–6/57	—	13.84	304.73	1,343.96	726.38	2,388.91
Capital outlay	—	—	—	1,233.74	365.65	1,599.39
7/57–6/58	227.62	—	225.03	249.69	483.08	1,185.42
7/58–6/59	0.52	—	260.83	382.26	317.81	961.42
Total	$3,942.98	$118.50	$1,448.88	$4,267.83	$3,354.98	$13,133.17
Per cent of total	30.0	0.9	11.2	32.4	25.5	—

(*b*) ENGINE NO. 2

Date	Propane	Valve Oil	Crank Oil	Labor, Trans.	Parts	Total
4/52–6/52	$1,290.20	—	$ 28.71	—	—	$1,318.91
7/52–6/53	342.01	$ 28.42	117.81	$ 82.86	$ 111.08	682.18
7/53–6/54	1,445.59	41.98	108.47	120.82	200.72	1,917.58
7/54–6/55	530.51	25.58	127.74	256.27	181.30	1,121.40
7/55–6/56	295.90	33.97	142.56	153.77	331.44	957.64
7/56–6/57	9.74	33.22	212.96	393.32	635.58	1,284.82
7/57–6/58	74.48	—	203.20	193.51	206.81	678.00
7/58–6/59	0.52	—	239.84	186.94	211.06	638.36
Total	$3,988.95	$163.17	$1,181.29	$1,387.49	$1,877.99	$8,598.89
Per cent of total	46.4	1.9	13.7	16.1	21.9	—

TABLE II.—Costs for Operating Engines 1 and 2

Item	Gas Engine Costs (¢/hr)													
	1952–53		1953–54		1954–55		1955–56		1956–57		1957–58		1958–59	
	No. 1	No. 2	No. 1	No. 2	No. 1	No. 2	No. 1	No. 2	No. 1	No. 2	No. 1	No. 2	No. 1	No. 2
Parts	1	2	7	3	3	4	7	8	20	12	12	4	7	4
Labor	2	2	1	3	2	6	7	2	36	8	6	4	8	4
Lubricating oil	3	3	3	4	3	4	8	4	9	5	5	4	6	5
Propane	5	7	43	34	5	12	2	7	—	—	5	1	—	—
Capital outlay	10	—	10	—	10	—	35	—	—	—	—	—	—	—
Depreciation	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Operator's time	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Total	37	30	80	60	39	42	75	37	81	41	44	29	37	29

The city of Santa Rosa has spent $34,703.62 to operate these engines for 62,753 hr or 55¢/hr. This includes the actual cost of operation, operator's time, and depreciation.

Is it worth it? During the seven and a fraction years covered in this paper, 102 mil cu ft of gas has been produced, and about 80 per cent of it or 1,269 cu ft/hr has been used in the engines. Based on the local utility rate and the heat value of its gas, the value of the sewage gas used to date is $22,149.73.

Comparative Costs

Estimated costs for natural gas and electricity are compared with costs for sewage gas in Table III. It was assumed that engine costs other than for fuel when adjusted to the same heat value would be the same whether sewage gas or natural gas was used. This, of course, may not hold true. Engine operating costs per million gallons varied from $1.55 to $0.38 with an average of $0.73. When the cost was $1.55/mil gal, LPG was used only 32.4 per cent of the time, so it can be seen that LPG is competitive only as a standby fuel. Using recorded costs for each item except fuel, operation on natural gas would have cost an estimated $1.31/mil gal, with a range of from $1.56 to $1.16.

The estimated electrical power consumption was based on the quantity of sewage pumped. Using the going rate, the comparative cost of electric power per million gallons pumped would have ranged from $1.52 to $1.84/mil gal pumped, with an average of $1.65.

It can be seen from these figures that

TABLE III.—Comparison of Costs for Engines Operated on Sewage Gas, Natural Gas, and Electricity

Year	Sewage Pumped (mil gal/mo)	Sewage Gas			Natural Gas			Electricity		
		Fuel* ($/mil gal)	Engine ($/mil gal)	Total ($/mil gal)	Fuel ($/mil gal)	Engine ($/mil gal)	Total ($/mil gal)	Avg hp	Rate ($/kwhr)	Cost ($/mil gal)
1952–53	269	0.29	0.21	0.50	1.04	0.21	1.25	47.5	0.0162	1.56
1953–54	211	1.26	0.29	1.55	1.03	0.29	1.32	40.5	0.0175	1.84
1954–55	299	0.55	0.30	0.85	0.94	0.30	1.25	50.5	0.0178	1.75
1955–56	349	0.10	0.51	0.61	0.97	0.51	1.48	55.0	0.0174	1.55
1956–57	308	0.00	0.79	0.79	0.77	0.79	1.56	66.1	0.0170	1.58
1957–58	345	0.07	0.38	0.45	0.79	0.38	1.17	54.5	0.0180	1.52
1958–59	353	0.00	0.38	0.38	0.78	0.38	1.16	56.0	0.0176	1.57
Avg.	305	0.32	0.41	0.73	0.90	0.41	1.31	52.9	0.0174	1.65

* Propane used as auxiliary fuel.

in Santa Rosa's case the use of gas engines was cheaper than any other system.

Conclusion

From the accumulated data, sewage pumping and air compression seem to be the most logical items of use for the gas engines. The experience so far confirms the correctness of the design selections.

Acknowledgments

It is seldom that a person writes a paper by himself. There are always those who give time and encouragement. The author thanks: Mr. Robert Van Guelpen, City Engineer, for the use of the accumulated data; Mr. Albert Hart, Sewage Plant Foreman, and all the operators who worked with these engines; and Mr. Carroll Reeves and Mr. Edward Poole of the Waukesha Pacific Equipment Company for their help in time of need. The author also thanks the mechanics who worked on these engines, for without their help this paper would not have been possible.

OPERATING TRAINING AT THE POTTSTOWN SEWAGE TREATMENT PLANT *

By Donald K. Jones

Director of Utilities, Pottstown, Pa.

Engineers are doing a tremendous job in sewage plant design and construction, but in spite of this there is still the frequent cry that a plant is not producing an acceptable effluent. It could be that the plant is underdesigned, or perhaps industrial wastes are interfering with the processes, but probably the commonest reason for failure is the lack of trained operating personnel.

If a plant is experiencing difficulty in producing an acceptable effluent, the superintendent should survey the municipality for sources of deleterious industrial wastes and carefully check each unit of his plant to see that it has adequate capacity and is designed properly. Sometimes a consulting engineer may be needed to do the latter. But if the trouble is not stemming from at least one of these sources, there is only one answer—poor operating practices. There is a definite relationship between a plant's results and the quality of its personnel.

Responsibility for Training

There have been many discussions on who should be responsible for training treatment plant operators. Some hold that engineering firms should assume this responsibility, others feel the state health department should be the instructing agency. In Pennsylvania, both play important training roles—the state sponsors periodic short courses in plant operation, and the engineering concerns instruct operators in the operation of newly built plants. These two groups also contribute much time and effort to the advancement of the Pennsylvania Sewage and Industrial Wastes Association. But even in the face of the great work done by both of these groups it seems that the main responsibility for training falls on the plant superintendent.

State sanitary engineers and consulting engineers are available to assist and advise the superintendent on advanced methods of operation, and to

* Presented at the 31st Annual Conference, Pennsylvania Sewage and Industrial Wastes Assn.; University Park, Pa.; Aug. 12–14, 1959.

aid him in solving the unusual problems that crop up in a treatment plant, but they cannot be held responsible for the training of operating personnel.

Training Fundamentals

Personnel

If good operators are to be developed, trainees must have the desire and ability to learn, and they must be physically fit. Another important quality is the ability to get along with fellow operators.

To obtain men with these qualifications the plant superintendent must have a positive recruitment program. The program should include prescribed requirements which must be met before a man is hired.

At Pottstown, every applicant is thoroughly investigated—this includes past employers, references, education, police records, and other pertinent information. Every recruit is hired for a six-month probational period, during which he is taught the operational procedures of the plant. Also during this period, he is carefully observed to determine if he will fit into the overall plant program.

In the early days, conditions at the Pottstown sewage treatment plant were like those of many plants the author visited—operators put in their designated work hours and went home, day in and day out, showing little or no interest in their work. It was alarming to see how little these operators knew about the how and why of treating sewage; and some of the operators had been working at the plant for many years. Naturally, over the years these men formed their own theories of how and why the plant operated. A classic example of this type of self-training came to light when a plating company accidentally discharged the contents of a nickel-cyanide tank to the sewer system and killed the organisms in the activated sludge. An operator was asked what he thought happened to the treatment process and what could be done about it. His answer was that bad supernatant from the digester caused the trouble and that the plant would not be in good shape until a three-day rain took place. His theory was that the increased infiltration would "wash out" the plant.

After a few similar encounters with the operators and an evaluation of the treatment plant and industries in the municipality, it was clear that a training program was needed.

Laying the Groundwork

Before any type of training program could be launched with a reasonable expectation of success, it was necessary to develop a sense of pride in the operators. This was accomplished by setting up a program for plant improvement. The equipment was overhauled and painted, the grounds were beautified, a chain of command was set up, and responsibilities were delegated. Too much cannot be said about raising morale with a paint brush.

After this original phase of training was well underway, periodic meetings were scheduled so that the operators could be kept informed on work being done at the plant, and also to give each operator an opportunity to express his views on operation. Much of the meeting time was devoted to developing a spirit of cooperation among the operators.

The meetings and the plant-rehabilitation program produced the desired results in a short period of time. It was truly gratifying to overhear one of the older operators giving a new operator a lecture on the proper disposal of cigaret butts.

Technical Training

Since it was considered desirable to make participation in the training program voluntary, it was necessary to gain the support and interest of the operators. To stimulate interest, the certification program in Pennsylvania,

and, more importantly, the mandatory certification of sewage plant operators in other states were discussed. There were also many discussions on the tremendous demand for sewage treatment facilities in this country, with the resultant need for trained operators. The operators were then informed that training would be necessary if they expected to pass the written examination or obtain another position in the sewage treatment field, and that if they were interested, a training program would be started at the plant. As was expected, every operator wanted to learn more about sewage treatment and become certified.

The text book, "Principles of Sewage Treatment," by Willem Rudolfs and published by the National Lime Association was selected as the basic book. Other notes, magazines, and books were used to supplement the basic text. The course material covered the following topics:

1. Reasons for sewage treatment,
2. Sources of sewage and industrial wastes,
3. Composition of sewage,
4. Methods of sewage treatment,
5. Devices used in sewage treatment,
6. Chlorination and its application in sewage treatment,
7. Sewage analyses and interpretation of results, with laboratory instructions,
8. Sewage treatment plant computations,
9. Sewage treatment plant safety,
10. Sewage treatment plant maintenance,
11. Sewage treatment plant administration, and
12. Public relations.

The training program also included: field trips to other sewage plants in the area; moving pictures on sewage treatment, obtained from the state health department's public relations division and other sources; and lecture-demonstrations by representatives of equipment companies.

The Pottstown training program operates on a continuing basis. Classes are very informal, and the operators are encouraged to take part in the discussion and to expound their own theories on problems at hand. Meetings are held in the afternoon, and are not in any way compulsory. The course is kept on an elementary level, but more advanced work will be attempted when the operators are ready for it. Of course, the superintendent must be constantly alert for signs of discouragement in any of his operators. When this occurs, he should deal with the individual personally, giving him a new incentive to go on with the training and prepare for certification.

Training Results

The training program has produced tangible results in that operating costs have been reduced through efficient operation. In addition, these men have made themselves more valuable to the municipality and they have benefited themselves by earning higher salaries.

One of the operators has accepted a position as superintendent of a sewage treatment plant in a neighboring community. This opportunity was afforded him because he applied himself in the training program and when the opportunity for advancement came, he was capable of filling the position. In this move he increased his salary substantially.

Conclusions

Every plant that employs more than one operator should have some sort of training program. It must be mentioned that before a training program can be started, it must have the support of the mayor and other city officials. In Pottstown, the borough manager was untiring in his efforts to see that the training program became a success.

A training program requires additional work on the part of the superintendent, but the results are well

worth the time spent. It is only through the cooperative effort of enlightened, trained personnel that the potential of a plant can be developed and utilized fully.

Acknowledgment

The author, not having had previous experience in teaching, required some assistance in developing a lesson plan and teaching technique. This assistance came from two men who deserve much credit for the success of the program —Mr. Clifford Smith of the State Health Department and Mr. James Lynham of the firm of Albright and Friel. These men supplied the author with teaching material and tips along with a great deal of moral support.

DEEDS AND DATA

Attention operators! It will be appreciated if copies of annual reports of both large and small sewage and industrial waste treatment plants are sent to the Federation office for abstracting in this section of the Journal. Please direct annual reports to: Water Pollution Control Federation, 4435 Wisconsin Ave., Washington 16, D. C.

"Words without actions are the assassins of idealism."—Herbert Hoover

Highlights from the Annual Reports of Austin, Tex., Bloom Township Sanitary District, Chicago Heights, Ill., Coral Gables, Fla., Greece, N. Y., Jackson, Mich., Melbourne and Metropolitan Board of Works, Melbourne, Australia, and Washington, D. C.

A. H. Ullrich, *Superintendent, Austin, Tex.;* J. E. Meers, *Superintendent, Bloom Township Sanitary District, Chicago Heights, Ill.;* W. C. Tims, *Superintendent, Coral Gables, Fla.;* Francis J. Cramer, *Superintendent, Greece, N. Y.;* R. A. Greene, *Superintendent, Jackson, Mich.;* J. A. McIntosh, *Chief Investigating and Designing Engineer, Melbourne and Metropolitan Board of Works, Melbourne, Australia;* and Hugh A. Schreiber, *Superintendent, Washington, D. C.*

Activated Sludge Plants

A modified activated sludge plant was put into operation at the District of Columbia. The few months the plant has been in operation is too short a period to permit any real evaluation of performance. So far, over-all BOD and SS removals have been in the range of from 70 to 75 per cent.

Operation

Operating data from five activated sludge plants are given in Table I.

Plant Grounds

The plant grounds at Jackson, Mich., are known as Northlawn Park, and so attractive is the area that one may find 300 or 400 people visiting at one

TABLE I.—Operating Results from Five Activated Sludge Plants

Treatment Plant	Operating Yr Ending	Est. Pop. Served	Sewage Volume				Sewage Temp. (°F)			Sewage Strength (mg/l)				Efficiency of Treatment (%)						Grit Removed (cu ft/mil gal)
			Avg (mgd)	Max Day (mgd)	Min Day (mgd)	Per Cap (gpd)	Avg	Max	Min	Influent		Effluent		Primary Unit		Secondary Unit		Over-all		
										BOD	SS	BOD	SS	BOD	SS	BOD	SS	BOD	SS	
1. Austin, Tex.	12/58	132,459[a]	15.6	18.4	—	—	75	—	—	197	188	21	22	—	—	—	—	89	88	1.8
2. Bloom Township, Ill.	4/59	60,000	6.3	—	—	105	—	—	—	215	374	208	85	33	57	59	44	75	76	—
3. Bloom Township, Ill.	4/58	50,000	6.7	—	—	134	—	—	—	54	297	69	92	40	54	46	35	67	70	—
4. Coral Gables, Fla.	6/59	15,150	2.6	—	—	172	—	—	—	—	—	—	—	—	—	—	—	97	91	—
5. Greece, N. Y.	12/58	23,600	1.5	2.6	1.3	66	—	—	—	200	175	50	50	15	38	71	53	75	71	7.2
6. Jackson, Mich.	6/59	50,000	10.9	16.6	6.0	218	60	73	44	111[b]	179	10	12	17	17	89	92	91	93	0.8

Treatment Plant	Primary Sedimentation				Activated Sludge								Disinfection	
	Surface Overflow Rate (gpd/sq ft)	Raw Sludge			BOD Loading (lb/day/1,000 cu ft)	Air Use (cu ft/lb of BOD removed)	Air Use (cu ft/gal of sewage)	Aeration Period (hr)	Return Sludge (%)	Mixed Liquor		Sludge Index	Cl_2 Dosage (mg/l)	Effluent Quality (MPN/ml)
		Volume (cu ft/mil gal of sewage)	Dry Solids (lb/mil gal of sewage)	Solids Conc. (%)						DO (mg/l)	SS (mg/l)			
1. Austin, Tex.	—	—	—	0.7	—	—	1.40	—[b]	44	—	1,826	1.03	—	—
2. Bloom Township, Ill.	450	1,670	—	—	—	—	—	—	—	—	—	—	—	—
3. Bloom Township, Ill.	480	1,610	—	—	—	—	—	—	—	—	—	—	—	—
4. Coral Gables, Fla.	—	500	937	3.0	—	—	—	—	—	—	—	—	6.7	47
5. Greece, N. Y.	—	—	—	—	38	—	—	7.0	30	3.1	2,100	1.25	4.8	—
6. Jackson, Mich.	—	476	1,315	4.5	23	871	0.59	4.8	21	2.3	2,420	3.0	—	—

[a] 1950 census population.
[b] Stabilizer time, 5.5 hr; mixing time, 33 min.

TABLE I.—*Continued*

Treatment Plant	Sludge Digestion														Sludge Filtration				Operating Cost ($/mil gal)
							Supernatant		Gas										
	VS Loading (lb/day/1,000 cu ft)	VS Red. (%)	Temp. (°F)	Vol. Acids (mg/l)	Alk. (mg/l)	pH	Volume (cu ft/mil gal of sewage)	Solids Conc. (mg/l)	Produced (cu ft/day/cap)	Produced (cu ft/lb VS fed)	Used (%)	Heat Value (Btu/cu ft)	CO_2 (%)	Dry Yield (psf/hr)	$FeCl_3$ Fed (%)	CaO Fed (%)	TS in Cake (%)	
1. Austin, Tex.	—[a]	—	77	—	—	6.7	—	5,000	—	—	—	—	—	—[c,d]	—	—	—	—
2. Bloom Township, Ill.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	57.10
3. Bloom Township, Ill.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	47.95
4. Coral Gables, Fla.	—	68	—	—	—	—	—	—	—	—	—	—	—	—	—	7.0	17	118.60
5. Greece, N. Y.	—	—	—	85–2,000	—	6.8–7.7	345	1,200	1.5	5.6	72	—	31	—[f]	—	—	—	151.50
6. Jackson, Mich.	27	47	83	—	—	—	—	—	0.9	—	83	—	—	—	—	—	—	38.77

[a] Excess sludge and supernatant treated in oxidation lakes.
[c] Drying beds used.
[d] Filters and incinerator out of service awaiting sludge supply.
[f] Drying beds and lagoons used.

time. What is a little unusual, though, is that the park attracts deer, too. One morning last winter four or five visiting deer ran across the grounds and leaped into the aeration tank; they were rescued uninjured.

Flow-Equalizing Tank

In 1952, the Austin, Tex., sewer department realized that an existing 36-in. outfall from a lift station to the treatment plant would soon be inadequate. They advised that serious consideration was being given to the early construction of a second line to parallel the existing one. At the time, plans and specifications for conversion of the treatment plant to a modification of the activated sludge process as well as a general enlargement were being prepared, but plans for the expansion did not anticipate an early increase in outfall capacity and it was realized that if the sewer department proceeded, the enlarged plant immediately would be taxed to its limit during peak flows.

In trying to find a way to increase the effective plant capacity, it occurred that a sewage-holding or flow-equalizing tank might be useful. In operating the tank, some of the sewage received during peak-flow hours would be stored and later released during hours of low flow. It was thought that if the tank could be made to work it would increase the effective plant capacity by as much as 50 per cent.

It was realized that the operation of a flow-equalizing tank probably would require special methods to control odors, septicity, and solids sedimentation. It seemed likely that odor problems could be controlled by ozone, that septicity could be controlled by aeration, and that excessive sedimentation of solids could be prevented by mechanical agitation. To test these methods and to collect design data, an 8,000-gal "pilot" tank was installed. The tank was equipped with a rotor-type mechanical agitator to prevent sludge

settling and a diffused-air system was installed to keep the sewage fresh. The tank was filled by the addition of raw sewage at a constant rate over a period of about 12 hr and was emptied at a constant rate in about 10 hr. Previous studies indicated this cycle of operation corresponded to the cycle which would result in the most effective use of a large tank located at the lift station. The test was made during the summer of 1953 when it was assumed that conditions for storing raw sewage would be the poorest.

Results of the pilot-plant operation indicated that a raw sewage holding tank was feasible. Solids were kept in suspension with mechanical agitators having very low power requirements, and sewage was kept fresh with as little as 0.1 cu ft of air per gallon of sewage held. BOD tests indicated that this small amount of air actually reduced the air subsequently required at the main plant. No odors were encountered in the pilot test so no odor control was needed. Nevertheless, separate tests on sewage odors were made using ozone for control. The results of these tests were also satisfactory.

Studies of the flow at the lift station showed that peak hourly flow rates were about 50 per cent higher than the average daily flows, but that the quantity of the sewage represented by this 50 per cent was only about 14 per cent of the total daily flow. From this it was reasoned that a 3-mil gal tank could equalize an average flow of 17.5 mgd having a peak hourly flow rate of at least 26.3 mgd. It was estimated that with a tank the combined peak flow rate at the plant would be 22.0 mgd. Fortunately, the maximum flow which the existing plant could accommodate was just equal to that amount.

The tank was completed in mid-1956. Immediately, a series of equipment failures was experienced. The ozone odor-control equipment was replaced with equipment of the catalytic-combustion type. This equipment was purchased on a trial basis, and for several months it also was subject to frequent mechanical failures. The tank was kept in service during 1957, but there were a few periods when it was shut down for adjustment of equipment. Satisfactory performance of all auxiliary equipment, including the odor control equipment, finally was achieved during Aug. 1957; the tank has been in satisfactory, continuous service since that date.

The final cost of the holding tank and auxiliary equipment was $206,477. At the time the tank was constructed, it was estimated that a new 36-in. outfall line to parallel the existing line would cost $160,200. Increasing the effective capacity of the existing line by 50 per cent, therefore, was worth a conservative $80,000. At that time it was also estimated that to increase the treatment plant capacity (exclusive of sludge disposal facilities, plant office, and laboratory) by 50 per cent would cost approximately $660,000. In view of this, it was reasoned that construction of the holding tank, costing $206,000, resulted in a gross capital cost savings of $740,000 or a net capital cost saving of $534,000.

Odor Control

With 25 lift stations in the Coral Gables system, odor control is a great concern. Control at this time is unique, but unproved; compressed air is added to the discharge side of pumps and ozone is used in the upper part of the structure. Chlorine is also added at some locations.

Sewer Construction

The Melbourne (Australia) and Metropolitan Board of Works is doing an extraordinary piece of experimental work in attempting to use power-boring methods for sewer construction. The Board's decision to go ahead with the work was prompted by the disproportionately high labor cost connected with the open-trench method.

The problems were many. First, a suitable pipe had to be developed; the usual bell and spigot pipe is unsuitable because the shape of the bell requires the bored hole to be larger in diameter than allowable. Needed was a pipe with a smooth outside wall and a flexible joint. So far, investigations indicate that concrete pipe can be made to fit these specifications, and experiments with clay pipe are underway. Field tests are confined to 6-in. sewers.

Auger

The second task was to develop a machine that would simultaneously rotate an auger and apply thrust to the cutting teeth of the bit in such a way that "wandering" would be eliminated. A machine has been designed that will fit into a 6-ft by 3-ft shaft, allowing room for an operator (Figure 1). It is driven by compressed air, with one air motor for rotation and another for thrust. The tube-like auger is in 3-ft lengths and grinds out a 1-in. annulus, or ring, the core remaining in the auger. Since the outside diameter of the auger is 9⅜ in., the diameter of the core is 7⅜ in. The inside diameter of the auger is 8⅛ in., so the core can move freely along it.

FIGURE 1.—Primary auger and cutting bit attached to the augering machine.

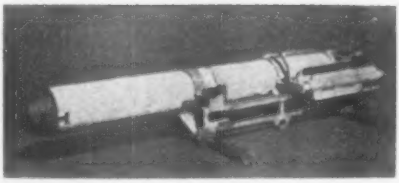

FIGURE 2.—Two lengths of pipe joined together on the pushing machine. A tapered nose piece is placed on the first pipe.

The next task was to find a way of extracting the cores from the auger. The cores from the Silurian rock in the test area weigh about 50 lb a lineal foot and have to be removed, at most, after three feet of augering to relieve the load on the auger. Methods for their removal have been devised.

Jointing Machine

The next stage was the evolution of a small machine for jointing the sections of pipe and pushing them through the tunnel to the next shaft (Figure 2). This machine has been built; like the auger, it is air powered. A procedure for testing each joint before it is pushed into the tunnel has also been developed.

Finally, a means had to be found for grouting the space between the surface of the pipe and the wall of the augered tunnel.

Results

Initial experimental augering in Silurian rock has indicated that a speed of penetration for a 3-ft piece of auger length takes between 6 and 15 min, depending on the texture of the rock. Allowing time for extraction of cores and reconnecting another 3-ft length of auger, the over-all speed will average 3 ft in about 30 min. Direction was maintained to within ½ in. of correct grade and alignment in an augered length of 30 ft.

No noticeable wear on the cutting bit

has occurred after 45 ft of experimental augering in two separate tunnels. Information as to actual wear on the cutting bits and helical strips, the correct peripheral speed of the auger, the desired thrust on the feed screw, and other technical details will be studied during further experimental augering.

The strike and dip of the formation in relation to the direction of augering affects the shape of the core pieces. Cores ranging from fragments to 2 ft 6 in. in length were recovered from the auger.

The results achieved to date are very encouraging and indicate that further research will lead to feasible methods of significantly reducing the costs of sewer construction in various types of ground.

Sludge Handling

Despite the good design of the Austin, Tex., activated sludge plant, operating results were generally poor during the period 1937–50, when the plant was operated along conventional lines. Following extensive laboratory and pilot-plant studies on activated sludge stabilization, the existing plant was converted to this new process (Biosorption) and placed in continuous operation during Apr. 1954. The conversion solved the operational problems, but it did not solve the excess sludge problem.

Sludge digestion and drying schemes were investigated, but all seemed so expensive that studies turned to the possibility of using oxidation lakes. Observations at San Antonio's Lake Mitchell led to the conclusion that several lakes designed for either parallel or series operation with recirculation and dilution facilities would solve the sludge problem.

About two miles downstream from the plant a 270-acre tract was purchased and construction of the first phase of the system was begun. This consisted of a sludge pumping station at the plant, a force main, a river intake, a mixing chamber, and a 41-acre lake. The work was completed in late 1956 and cost $350,000 which included $120,000 for the land.

Beginning in Dec. 1956, all excess sludge and all digester supernatant were diverted to the lake until Apr. 1957 when the steel sludge lines crossing the river were washed out. During this period the system operated very well. On Jan. 29, 1958, operations were resumed.

At the time the original 41-acre lake was constructed it was realized that its capacity would be taxed from the beginning so plans were readied to add an 85-acre and a 65-acre unit. Contract work on both lakes was finished late in 1958.

From Jan. 1958 to Jan. 1959 the 41-acre lake received nearly all excess sludge and all supernatant. The BOD loading was close to 4.6 lb/day/1,000 sq ft (200 lb/day/acre). This high loading gave some concern, but the continuing successful performance suggests that when all lakes are in operation (191 acres) the facilities will take care of twice the connected population. At present the sewage flow is 15.7 mgd.

The average BOD concentration in the effluent from the 41-acre pond during 1958 was 21 mg/l, with a low of 12 and a high of 41.

The cost of the second phase of the project will be about $225,000 (gravel has not yet been placed on the inside of the levees of the 65-acre basin). The entire cost of the sludge disposal system, including land, will be about $575,000. The cost of operating the lake system during 1958 is estimated at $4.80 per ton of dry solids. This unit cost will drop as sludge production increases.

LABORATORY SHORT COURSE FOR TREATMENT PLANT OPERATORS *

By M. A. Shapiro and E. Weisberg †

Associate Professor and Assistant Research Professor, Sanitary Engineering Section, Department of Public Health Practice, Graduate School of Public Health, University of Pittsburgh, Pittsburgh, Pa.

Treatment plant operators have a strong desire to learn more about their jobs. This desire is demonstrated time and again by the numerous examples of operators initiating or recommending training courses and the twin observations of: (*a*) attendance at short schools usually being higher than expected, and (*b*) operators, in many instances, taking training at a sacrifice of time and money. The subject has been the basis for many forums, surveys, and reports (1)(2)(3). At present there is agreement on the need for training, but there is no agreement about the kind of training to be given, the topics to be emphasized, or the frequency with which the course should be repeated. Moreover, it is unlikely that agreement will ever be possible because treatment methods and personnel are changing continually.

Organizing the Course

These thoughts were uppermost when the Western Operators Section of the Pennsylvania Sewage and Industrial Wastes Association and the Pennsylvania Health Department asked the Graduate School of Public Health to conduct a basic laboratory course for sewage treatment plant operators. Before final commitments were made, a questionnaire was sent out to obtain information concerning: the desirability of a basic laboratory course; ability to attend at the specified time (three hours every Saturday for eight weeks); type of plant, position held, and duration of employment; highest grade of school completed; and short courses previously attended. In addition, a list of common laboratory tests was submitted to potential participants, and they were asked to indicate which of the tests they were performing, whether they had any past experience with the tests, and which tests they would like to learn or review from the standpoint of method, technique, and interpretation. Thirty respondents were anxious and able to attend on the selected dates.

Unfortunately, the completed questionnaires revealed little discrimination in reply to the question about which tests should be selected. Almost every respondent desired instruction in all 30 tests listed. Obviously, this answer to the question was of no help in tailoring the course because it was impossible to cover all of the tests in the allowable time. In view of this, an effort was made to select appropriate subject matter on the basis of the nature of the treatment plant. As one might expect, the heterogeneity of the group offered another complication in course development. Of the 30 participants, 9 were from activated sludge plants, 3 from trickling filter plants, 9 from primary plants; of the remaining 9, 3 were consulting engineers, 3 were health department personnel, and 3 were operators of plants treating both sanitary and industrial wastes.

Subject Matter Selected

The subjects selected for the eight sessions are listed in Table I. To meet

* Presented at the 31st Annual Conference, Pennsylvania Sewage and Industrial Wastes Assn.; University Park, Pa.; Aug. 11-14, 1959.

† At present, Director-Sanitary Engineering, Pantech Engineers, Pittsburgh, Pa.

the objectives and to best utilize the time available, the course was organized and operated as follows:

1. Detailed step-wise instructions were prepared for each laboratory exercise. The procedures were discussed with the whole group before the exercise was performed.
2. Whenever possible, reagents and equipment were prepared and put in place ahead of the meeting time.
3. The 30 students were divided into 10 groups of 3 each, and there were from 3 to 5 staff members present to check on performance and answer questions.
4. Reading material for each exercise was selected a week in advance so that the students could become familiar with the terminology and techniques of the test prior to the session.
5. Homework was assigned, and the answers were corrected and discussed with the students.
6. At the end of the course a closed-book examination was given. The questions were divided into true-false, multiple-choice, and essay types. Questions were constructed in a way which demanded an understanding of the topic if successful answers were to be given.

Discussion

The value of the instruction is best measured by improved treatment plant operation. Unfortunately, it is too early to tell if measurable differences have resulted in the plants operated by the first group to complete the course. The only evaluation available now is the reaction of the group, and in this connection some have requested that a more advanced course be offered. Also, many of those who could not attend the first course have requested that they be given the opportunity to attend a repeat course.

Earlier, the mixed background of the group was pointed out, and this condition caused the staff to "switch gears," so to speak, during the sessions. Nevertheless, no great difficulty was encountered in presenting the factual material in a concise, basic manner.

Those who organized the course were guided by the principle that it is more important to emphasize the *why* rather than the *how* of an analytical test. This concept does not imply that it was hoped to teach the complete theory or the fine points of factors which may affect plant performance; it does mean that the teachers were not concerned solely or even predominantly with techniques, such as pipetting, titrating, and weighing. These proficiencies are acquired with practice. In addition, the *how* of an analytical method is adequately spelled out in "Standard Methods" (4).

In the one-hour lectures which preceded each laboratory period these general items were discussed: the importance of the test, the limitations and significance of the result, the possible sources of error, the reason certain procedures were employed in an analysis, and the necessity for careful technique.

Also discussed were items found in "Standard Methods" such as capital N and M (Normal and Molar), pH, and "$Na_2S_2O_3$," and the derivation of those formulas which by virtue of a group of multipliers one "magically" obtains the mg/l of a particular substance from a titration or weighing.

Experience to date corroborates that

TABLE I.—Course Schedule

Week Number	Test
1	Weighing
2	Solids
3	Solids continued, pH, standard solutions
4	Acid-base titration, alkalinity
5	DO, BOD, relative stability
6	Chlorine demand and residual
7	Sludge index, oxygen demand, microscope examination of activated sludge

of others which indicates there is a great willingness and the need on the part of the operators to learn basic chemistry and arithmetic. Emphasis was given to transforming a value obtained in an analytical test, usually in mg/l or mg, to such expressions as pounds of solids, volume of sludge, pounds of volatile solids, pounds of BOD, per cent efficiency, etc. Proficiency in arithmetic, however, was not a major objective of the course, not because it was considered unimportant, but because the subject was considered more suitable for inclusion in a lecture course on sewage treatment or even as a separate course. Correct calculations carried out on erroneous initial values (derived from faulty analytical technique) are no more meaningful than incorrect calculations. But even more important, there is little value derived from arriving at a correct figure of pounds of BOD if the operator has no understanding of the meaning and significance of the BOD concept itself. It was to this latter need that the major emphasis of the course was directed.

A nominal fee of $15 was charged to each participant. Having had no previous experience on the cost of conducting such a basic course, this sum was agreed upon by the teaching staff and the executive board of the Western Operators Section. The sum was placed in a separate fund in the Graduate School of Public Health budget and was utilized to replenish materials and supplies consumed during the conduct of the course. No salaries were paid out of the money received.

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2. Pierce, D. M., "Mandatory Operator Certification in Michigan." *Sewage and Industrial Wastes*, **31**, 5, 594 (May 1959).
3. "1953 Operators Forum." *Sewage and Industrial Wastes*, **26**, 5, 675 (May 1954).
4. "Standard Methods for the Examination of Water, Sewage, and Industrial Wastes." 10th Ed., Amer. Pub. Health Assn., New York (1955).

TIPS AND QUIPS

Color Removal *

A new method for removing color from caustic extract bleaching waste is under investigation at Louisiana State University. This process employs adsorption of the color bodies on a mass of hydrated lime which is integrated with the mill causticizing system in such a manner that it is re-dissolved in the white liquor, and ultimately burned in the black liquor furnace. Results to date indicate that the presence of the color bodies has little effect on either causticizing efficiency or settling. Laboratory tests are being made at a number of bleached kraft mills employing their individual caustic extract, reburned lime, and green liquor.

* From the Aug. 1959 Newsletter of the New England Interstate Water Pollution Control Commission.

100 Years Too Late †

A "bit of old St. Louis" was found by an emergency crew when it answered a complaint about water in the basement of a store.

Beneath a ladies' hat shop was a 12-ft deep basement, and below that was a 30-ft sub-basement with water 15 ft deep.

Inquiry by the crew disclosed that the sub-basement had been the storage area of the old Cherokee Winery dating back perhaps more than 100 years. Exploration showed brick tunnels, ap-

† From the Metropolitan St. Louis Sewer District (Nov. 1959).

proximately 15 ft high and 20 ft wide, extending eastward 200 ft or more, and southwardly 300 ft or more.

Fortunately, the water had nothing to do with neighboring sewers. Tests by the water department showed that it was ground water.

Zimmerman Process

On top of the news about the contracts for the construction of Zimmerman Process sludge disposal facilities at Chicago and Wheeling, comes word from Sterling Drug, Inc., that a Zimmerman Process Division has been formed within the firm.

The Chicago contract calls for the erection of four 50-ton units, and at Wheeling one 5.6-ton unit will be built (Figure 1). The contract price for Chicago is $11,870,000; at Wheeling it is $284,000.

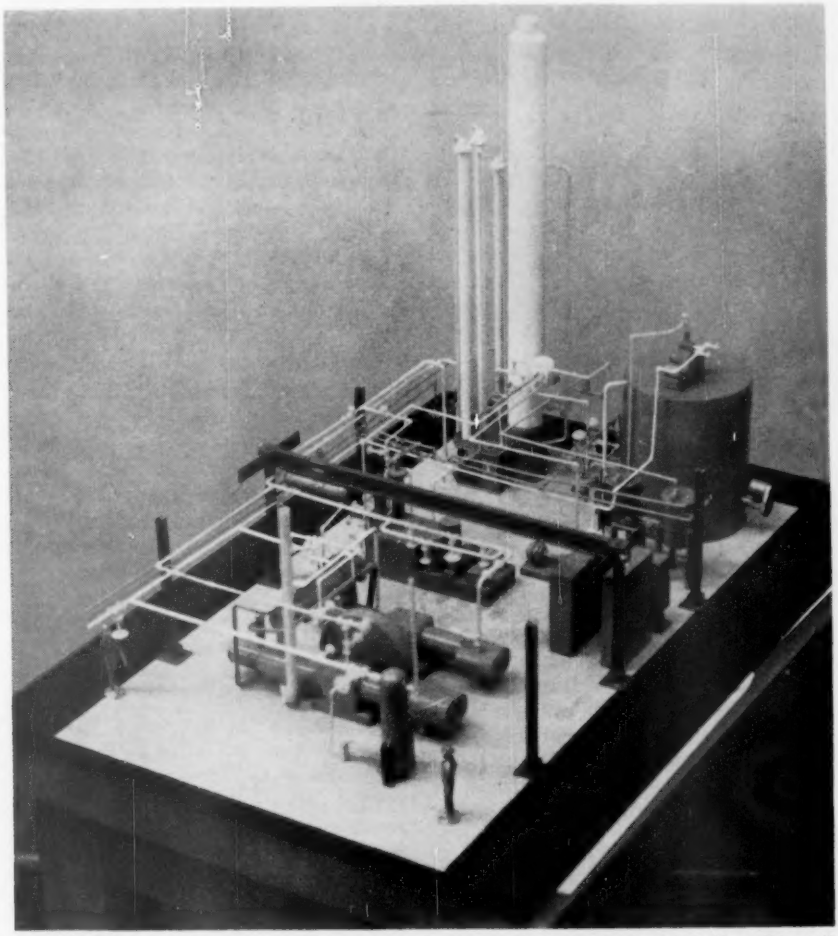

FIGURE 1.—Scale model of Zimmerman Process unit for Wheeling, W. Va. The tall tower in rear of picture is the reactor; the three tall structures immediately to the left of reactor are heat exchangers; the big tank in the rear is for sludge storage, and a grinder is on top of it. In the left center is a high-pressure pump; in the right center is the control center. An air compressor and expander are shown in the foreground.

Editorial

THE 1960 MEMBERSHIP DIRECTORY

This issue of the Federation Journal marks another first in service and importance to the membership. The Federation Membership Directory, while only a few years old in its present form, has become well established as the only full compilation of those in the wastewater field.

The March issue of the Federation Journal has been the traditional month for inclusion of the Yearbook and Directory. To those who have watched this issue in recent even-numbered years, the shrinkage of editorial content has been noticeable as the Directory required an increasing number of pages with Federation Membership growth. To continue this trend would have produced a further unbalance. The choice of two parts for this March issue, therefore, was made to give Journal readers the most possible service. This separation has the additional important advantage of making the Yearbook and Directory handier to the user. It will be especially convenient to travelers or any who may prefer to have this Yearbook and Directory separate from his other Journals.

The financing of two issues was no small part of the production problem. Regular Journal advertisers were asked to use space in this special issue and the response was most gratifying. The use of these pages by advertisers is particularly attractive because of recurring use of the Directory Issue throughout its two-year life.

The compilation of such a Directory involves so many details that complete accuracy is very difficult. For this reason all Federation members have been requested to send personal information early to the Federation office as well as to their Member Association Secretary so that maximum accuracy may be attained. To those who may have an incorrect entry in this Directory, we apologize and hope our future efforts will be improved.

In the Federation's 32 years of progress, a membership listing has been included annually but this listing has undergone a material evolution. Prior to 1948, there were annual listings of the membership by Member Associations. Growth made this method of listing less and less useful, so that in 1948 the consolidated Membership Directory was introduced. This plan of listing was used annually through 1952.

In 1954, the present schedule of printing a complete consolidated Membership Directory with the Yearbook in the March issue of alternate years was adopted. The March issue of odd-numbered years contained only a supplemental list of new members for the previous year.

In 1956, the consolidated Membership listing was augmented by the geographical listing, which has proved to be of great value.

It should be noted that the Membership Directory is limited to Federation Membership and does not list the approximately 1,400 non-member subscribers to your Federation Journal. Your comment on this form of the Directory is earnestly solicited. Only by having your reaction can we be guided in similar future compilations.

R. E. F.

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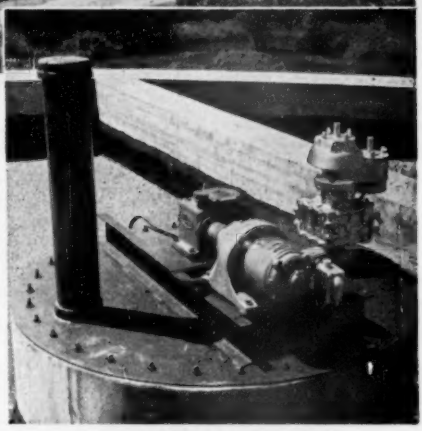

"VAREC" Fig. No. 5800C
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INDEX

Volumes 21-30, 1949-1958

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The new Ten-Year Index is a companion to the previous Twenty-Year Index to the first 20 volumes of SEWAGE WORKS JOURNAL for 1928–1948, copies of which are still available from the Federation office.

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Proceedings of Member Associations

PENNSYLVANIA SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The 31st Annual Conference of the Pennsylvania Sewage and Industrial Wastes Association was held at University Park, Pa., Aug. 12–14, 1959.

The technical sessions started with concurrent round table discussions on the subjects of plant operation and industrial wastes.

On successive days the following topics were discussed: joint treatment of sewage under intermunicipal agreements, biological engineering principles applied to activated sludge, Zimmerman process, disposal and recovery of inorganic metal sludges, operator educational needs, in-plant training, laboratory short course planning, radioactivity in sewage, and water quality management.

Separate breakfast meetings brought together those interested in laboratory control and industrial wastes. Immediately prior to the first technical session, the certification examinations were given.

At the Annual Dinner, FSIWA Executive Secretary Ralph E. Fuhrman presented the Bedell Award for extraordinary service to the Association to Roy F. Weston, Consulting Engineer of Newtown Square. The Hatfield Award for outstanding treatment plant operation and management went to Paul N. Longley, Superintendent, Radnor-Haverford Sewage Treatment Plant, Havertown.

(*Continued on page 130a*)

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WATER POLLUTION CONTROL FEDERATION

4435 Wisconsin Avenue Washington 16, D.C.

At the business session these officers were elected to serve during the year 1959–60:

President: Samuel I. Zack, Harrisburg.
1st Vice-President: Alfred A. Estrada, Drexel Hill.
2nd Vice-President: John Yenchko, Greensburg.
Secretary-Treasurer: J. R. Harvey, Meadville.

J. R. Harvey
Secretary-Treasurer

GEORGIA WATER AND SEWAGE ASSOCIATION

The Georgia Water and Sewage Association held its Annual Meeting in conjunction with the 28th Annual Georgia Water and Sewage School, Sept. 9–11, 1959. The meeting was held on the grounds of the Georgia Institute of Technology, Atlanta, Ga. The total registration was 422.

The program, as usual, was of excellent quality, and among the topics discussed were: water resources and quality, utility management, planning for emergencies, pulp and paper waste treatment, textile waste treatment, chlorination, digester operation, sewer maintenance, pumping, and utility relocations.

At the business meeting, important constitutional changes were made which resulted in the formation of a Wastes Section within the Association. This new Section elected the following officers to serve during the year 1959–60:

Chairman: C. E. Drummond, Jr., Atlanta.
Vice-Chairman: L. R. Simonton, Griffin.
Secretary-Treasurer: R. S. Ingols, Atlanta.
Director: M. B. Nixon, Atlanta.

R. S. Ingols
Secretary-Treasurer

(*Continued on page 133a*)

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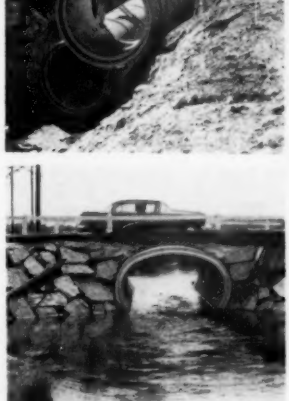

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WATER POLLUTION CONTROL PRODUCT GUIDE

This list of products and services is offered as an information aid. The list was derived by solicitation from those firms listed. The JOURNAL will make every effort to keep this list current with the help of members and advertisers. All Associate Members and all advertisers for the past calendar year are included. Many of the services and products are advertised in this issue. For an alphabetical listing see Index to Advertisers in back of Journal.

Aerators (*also see* Diffusers, Air)
Alpha Ltd. (Switzerland)
American Well Works
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Graver Water Conditioning Co.
Infilco Inc.
Link-Belt Co.
Pacific Flush Tank Co.
Penberthy Mfg. Co., Div. of Buffalo-Eclipse Corp.
Permutit Co., Div. of Pfaudler-Permutit Inc.
Smith & Loveless, Inc.
Walker Process Equipment Inc.
Wemco Div., Western Machinery Co.
Yeomans Brothers Co.
Zimmer & Francescon

Agitators
Link-Belt Co.

Air Cleaning Equipment
Westinghouse Electric Corp.

Air Compressors (*also see* Blowers, Compressors, and Fans)
Chicago Pump Co.
Fairbanks, Morse & Co.
Komline-Sanderson Engr. Corp.
Worthington Corp.
Yeomans Brothers Co.

Air Diffusers (*see* Diffusers, Air)

Asbestos Cement Pipe Products
Filtration Equipment Corp.
Industrial Materials Co.
Johns-Manville Sales Corp.
Keasbey & Mattison Co.

Ash Handling Equipment
Link-Belt Co.

Automobiles and Trucks
Vulcan Materials Co.

Bearings
Link-Belt Co.

Bins, Storage (*see* Tanks)

Biologists (*see* Directory of Engineers)

Blowers (*also see* Air Compressors, Compressors, and Fans)
Chicago Pump Co.
Roots-Connersville Blower, Div. of Dresser Industries Inc.
Yeomans Brothers Co.
Zimmer & Francescon

Boilers
Combustion Engineering, Inc.

Building Maintenance Equipment and Supplies
Homestead Valve Mfg. Co.

Cast Iron Pipe Products
American Cast Iron Pipe Co.
Cast Iron Pipe Research Assn.
Industrial Materials Co.
U. S. Pipe & Foundry Co.
R. D. Wood Co.

Cement (*see* Concrete)

Centrifuging Equipment
Bird Machine Co.

Chains
Chain Belt Co.
Link-Belt Co.
Webster Mfg., Inc.

Chemical Feed Equipment
Builders-Providence Div., B-I-F Industries
Eimco Corp.
Fischer & Porter Co.
Graver Water Conditioning Co.
Infilco Inc.
Jeffrey Mfg. Co.
Komline-Sanderson Engr. Corp.
Link-Belt Co.
Omega Div., B-I-F Industries
Permutit Co., Div. of Pfaudler-Permutit Inc.
Proportioneers Div., B-I-F Industries
Wallace & Tiernan Inc.

Chemicals
Cloroben Chemical Corp.
Dow Chemical Co.
Fisher Scientific Co.
General Chemical Div., Allied Chemical Corp.
Tennessee Corp.
Vulcan Materials Co.

Chemists (*see* Directory of Engineers)

Chlorination Equipment
Builders-Providence Div., B-I-F Industries
Everson Mfg. Co.
Fischer & Porter Co.
Graver Water Conditioning Co.
Wallace & Tiernan Inc.
Zimmer & Francescon

Clarifier Equipment (*also see* Sedimentation Equipment)
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Chain Belt Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Graver Water Conditioning Co.
Hardinge Co., Inc.
Infilco Inc.
Jeffrey Mfg. Co.
Komline-Sanderson Engr. Corp.
Lakeside Engineering Corp.
Link-Belt Co.
Permutit Co., Div. of Pfaudler-Permutit Co.
Walker Process Equipment Inc.
Yeomans Brothers Co.
Zimmer & Francescon

Clay Pipe Products
Industrial Materials Co.
National Clay Pipe Mfrs., Inc.
Wedge-Lock Clay Pipe Mfrs., Inc.

Coatings and Linings (Pipe and Tank)
Amercoat Corp.
Centriline Corp.
Inertol Co., Inc.
Koppers Co., Inc.
National Water Main Cleaning Co.
Perry-Austen Mfg. Co.
Pittsburgh Coke & Chemical Co.
Stebbins Engr. & Mfg. Co.
Vulcan Materials Co.

Comminutors (*also see* Shredders and Grinders)
Alpha Ltd. (Switzerland)
American Well Works
Chicago Pump Co.
Dorr-Oliver Inc.
Gruendler Crusher & Pulverizer Co.
Infilco Inc.
Jeffrey Mfg. Co.
Smith & Loveless, Inc.
Walker Process Equipment Inc.
Worthington Corp.

Compressors
Chicago Pump Co.
Fairbanks, Morse & Co.
Komline-Sanderson Engr. Corp.
Roots-Connersville Blower, Div. of Dresser Industries Inc.
Worthington Corp.
Yeomans Brothers Co.

Computers
Minneapolis-Honeywell Regulator Co., Brown Instruments Div.

Concentrators (*see* Sludge Concentrators)

Concrete
Portland Cement Assn.
Vulcan Materials Co.

Concrete Pipe Products
American Concrete Pressure Pipe Assn.
American-Marietta Co.
Gray Concrete Pipe Co., Inc.
Industrial Materials Co.
Lock Joint Pipe Co.
Portland Cement Assn.
Price Bros. Co.
Vulcan Materials Co.

Construction Equipment
Chain Belt Co.
Eimco Corp.
Worthington Corp.

Controls (*also see* Instruments, Recording and Control)
Bailey Meter Co.
Builders-Providence Div., B-I-F Industries

FLORIDA SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The 10th Joint Conference of the Florida Sewage and Industrial Wastes Association and the Florida Section of the American Water Works Association was held at the Hillsboro Hotel, Tampa, Fla., on Nov. 15–18, 1959. The registration for the meeting was 360.

The keynote address, by Dr. Thorndyke Saville, was a highlight of the Monday session, and it effectively served to introduce the wide range of topics discussed in later sessions. Among the papers dealing with water pollution control activities were:

"Recent Observations of Experimental Waste Stabilization Ponds," by James H. McDermott and William B. Horning, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio.

"Certification and Training of Water and Sewage Plant Operators," by George W. Burke, Jr., U. S. Public Health Service, Washington, D. C.

"Rated Aeration," by John Tapleshay, Chicago Pump Co., Atlanta, Ga.

"Florida Water Resources—1959," by John W. Wakefield, Department of Water Resources, Tallahassee, Fla.

"Small Sewage Treatment Plants," by R. C. Cloppen, Yeomans Brothers Co., Melrose Park, Ill.

"Sewers on the Sun Coast Area of Florida," by Arthur J. Birchall, Smith and Gillespie, Jacksonville, Fla.

"The Results of Ten Years of Sanitary Engineering Research at the University of Florida," by Thomas deS. Furman and F. W. Gilcreas, University of Florida, Gainesville, Fla.

"Disposal of Wastes from the Phosphate Industry," by Randolph G. Specht, American Agricultural Chemical Co., Ft. Pierce, Fla.

(*Continued on page 135a*)

SNOW GATES
for
SEWAGE TREATMENT PLANTS

All types of cast iron gates manufactured in either square or circular opening in sizes up to and including 72 inches.

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Permutit Co., Div. of Pfaudler-Permutit Co. Inc.
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Wallace & Tiernan Inc.
Westinghouse Electric Corp.
Worthington Corp.

Conveyors
American Well Works
Chain Belt Co.
Chicago Pump Co.
Jeffrey Mfg. Co.
Link-Belt Co.
Stuart Corp.
Webster Mfg., Inc.

Corrosion Protection
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Chicago Pump Co.
Inertol Co., Inc.
Johns-Manville Sales Corp.
Koppers Co., Inc.
Perry-Austen Mfg. Co.
Stebbins Engr. & Mfg. Co.
Wallace & Tiernan Inc.

Couplings
Link-Belt Co.

Diffusers, Air (*also see* Aerators)
Alpha Ltd. (Switzerland)
American Well Works
Carborundum Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Infilco Inc.
Lakeside Engineering Corp.
Link-Belt Co.
Pacific Flush Tank Co.
Penberthy Mfg. Co., Div. of Buffalo-Eclipse Corp.
Walker Process Equipment Inc.
Wemco Div., Western Machinery Co.
Zimmer & Francescon

Diffusers, Gas (*also see* Aerators)
American Well Works
Carborundum Co.
Chicago Pump Co.
Eimco Corp.
Infilco Inc.
Walker Process Equipment Inc.
Yeomans Brothers Co.

Digestion Tank Equipment
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Gorman-Rupp Co.
Hardinge Co., Inc.
Infilco Inc.
Jeffrey Mfg. Co.
Lakeside Engineering Corp.
Link-Belt Co.
Pacific Flush Tank Co.
Smith & Loveless, Inc.
Vapor Recovery Systems Co.
Walker Process Equipment Inc.
Yeomans Brothers Co.
Zimmer & Francescon

Distributors, Rotary
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American Well Works
Ralph B. Carter Co.
Dorr-Oliver Inc.
Eimco Corp.
Infilco Inc.
Lakeside Engineering Corp.
Link-Belt Co.
Pacific Flush Tank Co.
Smith & Loveless, Inc.
Walker Process Equipment Inc.
Yeomans Brothers Co.
Zimmer & Francescon

Dryers
Alpha Ltd. (Switzerland)
Combustion Engineering, Inc.
Eimco Corp.
Hardinge Co., Inc.
Komline-Sanderson Engr. Corp.
Link-Belt Co.
Nichols Engr. & Research Corp.
Stuart Corp.

Ejectors
Komline-Sanderson Engr. Corp.
Smith & Loveless, Inc.
Tex-Vit Supply Co.
Yeomans Brothers Co.

Engineers (*see* Directory of Engineers)

Engines (Sludge Gas and Petroleum Fuels)
Climax Engine Mfg. Co.
Fairbanks, Morse & Co.
Waukesha Motor Co.
Worthington Corp.

Fans (*also see* Air Compressors, Blowers, and Compressors)
Chicago Pump Co.
Lakeside Engineering Corp.
Westinghouse Electric Corp.

Filter Equipment, Trickling
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Dorr-Oliver Inc.
Dow Chemical Co.
Eimco Corp.
Filtration Equipment Corp.
Industrial Materials Co.
Infilco Inc.
Keasbey & Mattison Co.
Komline-Sanderson Engr. Corp.
Lakeside Engineering Corp.
Nichols Engr. & Research Corp.
Pacific Flush Tank Co.
Smith & Loveless, Inc.
Trickling Filter Floor Inst.
Walker Process Equipment Inc.
Yeomans Brothers Co.
Zimmer & Francescon

Filter Materials
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Filtration Equipment Corp.
Graver Water Conditioning Co.
Industrial Materials Co.
Johns-Manville Sales Corp.
Vulcan Materials Co.

Filters, Diatomaceous Earth
Graver Water Conditioning Co.
Yeomans Brothers Co.

Filters, Vacuum (*also see* Vacuum Filters)
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Eimco Corp.
Proportioneers Div., B-I-F Industries

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Graver Water Conditioning Co.
Hardinge Co., Inc.
Infilco Inc.
Jeffrey Mfg. Co.
Lakeside Engineering Corp.
Link-Belt Co.
Stuart Corp.
Walker Process Equipment Inc.
Webster Mfg., Inc.
Zimmer & Francescon

Flotation Equipment
Chain Belt Co.
Dorr-Oliver Inc.
Eimco Corp.
Graver Water Conditioning Co.
Komline-Sanderson Engr. Corp.
Yeomans Brothers Co.

Flow Measurement
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Burgess-Manning Co., Penn Instruments Div.
Filtration Equipment Corp.

Gas Control Equipment
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Burgess-Manning Co., Penn Instruments Div.
Ralph B. Carter Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Foxboro Co.
Homestead Valve Mfg. Co.
Pacific Flush Tank Co.
Rockwell Mfg. Co.
Vapor Recovery Systems Co.
Walker Process Equipment Inc.
Zimmer & Francescon

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Gas Holders, Boilers, and Appurtenances
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Pittsburgh-Des Moines Steel Co.
Walker Process Equipment Inc.

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Keasbey & Mattison Co.

Gates
Armco Drainage & Metal Products, Inc.
Filtration Equipment Corp.
Industrial Materials Co.
Snow Gates & Valves, Inc.
Webster Mfg., Inc.

Generators
Climax Engine Mfg. Co.
Fairbanks, Morse & Co.
General Electric Co.
Westinghouse Electric Corp.
Worthington Corp.

Grease Control Materials
Cloroben Chemical Corp.

Grinders (*also see* Shredders and Grinders)
Alpha Ltd. (Switzerland)
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Dorr-Oliver Inc.
Gruendler Crusher & Pulverizer Co.
Jeffrey Mfg. Co.
Yeomans Brothers Co.

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American Well Works
Chain Belt Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Infilco Inc.
Jeffrey Mfg. Co.
Link-Belt Co.
Stuart Corp.
Walker Process Equipment Inc.
Webster Mfg., Inc.
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Successful operation of the activated sludge process depends upon efficient and economical aeration. Compared to the 4 to 5% absorption by porous plates on mechanical systems, Penberthy Aeration Ejectors provide 20 to 25% oxygen absorption while using 40% LESS horsepower.

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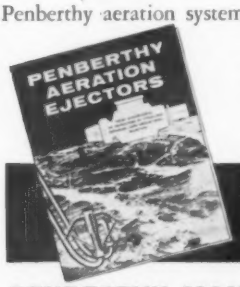

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Division of Buffalo-Eclipse Corporation

"The Effect of Industrial Wastes on Florida's Ground Water," by Robert O. Vernon, Geological Survey, Tallahassee, Fla.

"Federation Affairs," by WPCF President, Mark D. Hollis.

Retiring Director John Wakefield presented a mimeographed report covering his activities during his term of office.

The new officers for 1959–60 are:

President: Clifford M. Courson, Tampa.

Vice-President: M. E. Dawkins, Jacksonville.

Secretary-Treasurer: Arthur R. Finney, Jr., Miami.

ARTHUR R. FINNEY, JR.
Secretary-Treasurer

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General Electric Co.
Infilco Inc.
Link-Belt Co.
Pacific Flush Tank Co.
Walker Process Equipment Inc.

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Morse Boulger, Inc.
Nichols Engr. & Research Corp.
Pittsburgh-Des Moines Steel Co.
Walker Process Equipment Inc.

Ion-Exchange Equipment
Permutit Co., Div. of Pfaudler-Permutit Inc.

Insect Control
Cloroben Chemical Corp.
Leeco Chemical Co., Div. of Leeco Gas & Oil Co.

Inspection, Sewers
Centriline Corp.
Industrial Pipe Repair Corp.
National Water Main Cleaning Co.

Instruments, Recording and Control (*also see* Controls and Recorders)
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Builders-Providence Div., B-I-F Industries
Burgess-Manning Co., Penn Instruments Div.
Fischer & Porter Co.
Fisher Scientific Co.
Foxboro Co.
General Electric Co.
Infilco Inc.
Minneapolis-Honeywell Regulator Co., Brown Instruments Div.
Rockwell Mfg. Co.
Wallace & Tiernan Inc.
Westinghouse Electric Corp.

Jointing Materials
American Concrete Pressure Pipe Assn.
Gray Concrete Pipe Co., Inc.
Keasbey & Mattison Co.
National Clay Pipe Mfrs., Inc.
Perry-Austen Mfg. Co.
Stebbins Engr. & Mfg. Co.
Wedge-Lock Clay Pipe Mfrs.

Joints, Mechanical
American Cast Iron Pipe Co.
Johns-Manville Sales Corp.
Smith-Blair, Inc.
U. S. Pipe & Foundry Co.
Wedge-Lock Clay Pipe Mfrs.

Laboratory Equipment and Supplies
Filtration Equipment Corp.
Fisher Scientific Co.
General Chemical Div., Allied Chemical Corp.
Stuart Corp.

Lift Stations
Smith & Loveless, Inc.
Tex-Vit Supply Co.

Lighting Fixtures
Westinghouse Electric Corp.

Lubricants
Homestead Valve Mfg. Co.
Johns-Manville Sales Corp.

Lumber
Vulcan Materials Co.

Manhole and Inlet Castings
American-Marietta Co.
Vapor Recovery Systems Co.
Vulcan Materials Co.

Masonry Building Materials
American-Marietta Co.
Portland Cement Assn.
Price Bros. Co.
Vulcan Materials Co.

Meter Boxes
Johns-Manville Sales Corp.

Meters (Sewage, Sludge, Water, Air, and Gas)
Bailey Meter Co.
Builders-Providence Div., B-I-F Industries
Burgess-Manning Co., Penn Instruments Div.
Ralph B. Carter Co.
Filtration Equipment Corp.
Foxboro Co.
Infilco Inc.
Minneapolis-Honeywell Regulator Co., Brown Instruments Div.
Rockwell Mfg. Co.
Roots-Connersville Blower, Div. of Dresser Industries Inc.
Simplex Valve and Meter Co.
Worthington Corp.

Mixing Devices
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Chain Belt Co.
Dorr-Oliver Inc.
Eimco Corp.
Infilco Inc.
Jeffrey Mfg. Co.
Walker Process Equipment Inc.
Wemco Div., Western Machinery Co.

Motors
Chicago Pump Co.
Fairbanks, Morse & Co.
General Electric Co.
Link-Belt Co.
Westinghouse Electric Corp.
Worthington Corp.

Odor Control Materials
Airkem Inc.
Cloroben Chemical Corp.
Florasynth Laboratories, Inc.
Tennessee Corp.
Wallace & Tiernan Inc.

Odor Counteractants
Airkem Inc.

Package Treatment
Chain Belt Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Infilco Inc.
Municipal Service Co.
Smith & Loveless, Inc.
Yeomans Brothers Co.

Packing
Johns-Manville Sales Corp.
Keasbey & Mattison Co.

Paints and Protective Coatings
Amercoat Corp.
Inertol Co., Inc.
Koppers Co., Inc.
Perry-Austen Mfg. Co.
Pittsburgh Coke & Chemical Co.
Smith & Loveless, Inc.
Stebbins Engr. & Mfg. Co.

Pipe, Asbestos Cement
Industrial Materials Co.
Johns-Manville Sales Corp.
Keasbey & Mattison Co.

Pipe, Cast Iron
American Cast Iron Pipe Co.
Cast Iron Pipe Research Assn.
Industrial Materials Co.
U. S. Pipe & Foundry Co.
R. D. Wood Co.

Pipe, Clay
Industrial Materials Co.
National Clay Pipe Mfrs., Inc.
Wedge-Lock Clay Pipe Mfrs.

Pipe Cleaning
Centriline Corp.
Cloroben Chemical Corp.
Flexible Inc.
Homestead Valve Mfg. Co.
National Water Main Cleaning Co.
W. H. Stewart, Inc.

Pipe Coatings and Linings
Amercoat Corp.
American Pipe & Construction Co.
Centriline Corp.
Koppers Co., Inc.
National Water Main Cleaning Co.
Perry-Austen Mfg. Co.
Stebbins Engr. & Mfg. Co.
Vulcan Materials Co.

Pipe, Concrete
American Concrete Pressure Pipe Assn.
American-Marietta Co.
American Pipe & Construction Co.
Gray Concrete Pipe Co., Inc.
Lock Joint Pipe Co.
Portland Cement Assn.
Price Bros. Co.
Vulcan Materials Co.

Pipe, Fiber
Brown Co.

Pipe Fittings
American Cast Iron Pipe Co.
Cast Iron Pipe Research Assn.
Keasbey & Mattison Co.
Price Bros. Co.
Smith-Blair, Inc.
U. S. Pipe & Foundry Co.
Wedge-Lock Clay Pipe Mfrs.
R. D. Wood Co.

Pipe Jointing Materials (*see* Jointing Materials)

Pipe, Plastic
Amercoat Corp.
Evanite Plastic Co.

Pipe, Repairs
Centriline Corp.
Industrial Pipe Repair Corp.
Smith-Blair, Inc.

Pipe, Steel
American Pipe & Construction Co.
Armco Drainage & Metal Products, Inc.
Keasbey & Mattison Co.

Plastic Pipe Products
Amercoat Corp.
Evanite Plastic Co.
Keasbey & Mattison Co.

Publications
Rheinhold Publishing Co.
John Wiley & Sons, Inc.

Pump Controls
Builders-Providence Div., B-I-F Industries
Burgess-Manning Co., Penn Instruments Div.
Chicago Pump Co.
Fischer & Porter Co.
Foxboro Co.
General Electric Co.
Minneapolis-Honeywell Regulator Co., Brown Instruments Div.
Rockwell Mfg. Co.
Smith & Loveless, Inc.
Tex-Vit Supply Co.
Westinghouse Electric Corp.
Worthington Corp.
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WPCF PUBLICATIONS

MANUALS OF SEWAGE AND INDUSTRIAL WASTES PRACTICE

Manual Number	Title	Price to Members*	Price to Non-Members*
1	Safety in Wastewater Works	$0.75	$1.50
2	Utilization of Sewage Sludge as Fertilizer	0.75	1.25
3	Municipal Sewer Ordinances (Revised)	—†	—†
4	Chlorination of Sewage and Industrial Wastes	1.00	1.25
5	Air Diffusion in Sewage Works	1.00	1.25
6	Units of Expression for Wastes and Waste Treatment	0.25	0.50
7	Sewer Maintenance	1.00	1.50
	Multiple wire binder for above manuals	2.00	2.00
8	Sewage Treatment Plant Design	3.50	7.00
9	Design and Construction of Sanitary and Storm Sewers	3.50	7.00
	Uniform System of Accounts for Sewer Utilities (revised)	—†	—†

OTHER FEDERATION PUBLICATIONS

INDEX, SEWAGE WORKS JOURNAL, Volumes 1–20, 1928–1948 (Subject, Author, and Geographical), buckram, $3.00.

INDEX, SEWAGE AND INDUSTRIAL WASTES, Volumes 21–30, 1949–1958 (Subject, Author, and Geographical), buckram, $4.00; paper, $3.00.

GLOSSARY—WATER AND SEWAGE CONTROL ENGINEERING, paper cover, $1.00.

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WATER POLLUTION CONTROL FEDERATION
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Pumps, Airlift
Walker Process Equipment Inc.

Pumps, Chemical Feed
Proportioneers Div., B-I-F Industries

Pumps, Gas
Roots-Connersville Blower, Div. of Dresser Industries Inc.

Pumps, Grit
Nagle Pumps, Inc.

Pumps, Sewage
Alpha Ltd. (Switzerland)
American Well Works
Chicago Pump Co.
Eimco Corp.
Fairbanks, Morse & Co.
Gorman-Rupp Co.
Infilco Inc.
Marlow Pumps, Div. of Bell & Gossett Co.
Smith & Loveless, Inc.
Wallace & Tiernan Inc.
Wemco Div., Western Machinery Co.
Worthington Corp.
Yeomans Brothers Co.
Zimmer & Francescon

Pumps, Sludge
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Fairbanks, Morse & Co.
Gorman-Rupp Co.
Hardinge Co., Inc.
Infilco Inc.
Komline-Sanderson Engr. Corp.
Marlow Pumps, Div. of Bell & Gossett Co.
Nagle Pumps, Inc.
Wallace & Tiernan Inc.
Wemco Div., Western Machinery Co.
Worthington Corp.
Yeomans Brothers Co.
Zimmer & Francescon

Pumps, Vacuum
Roots-Connersville Blower, Div. of Dresser Industries Inc.

Pumps, Water
American Well Works
Ralph B. Carter Co.
Chain Belt Co.
Chicago Pump Co.
Eimco Corp.
Fairbanks, Morse & Co.
Gorman-Rupp Co.
Marlow Pumps, Div. of Bell & Gossett Co.
Wallace & Tiernan Inc.
Worthington Corp.
Yeomans Brothers Co.
Zimmer & Francescon

Radiation Monitoring Equipment
Westinghouse Electric Corp.

Radios, Mobile
General Electric Co.

Recorders (*also see* Instruments, Recording, and Control)
Builders-Providence Div., B-I-F Industries
Burgess-Manning Co., Penn Instruments Div.
Fischer & Porter Co.
Fisher Scientific Co.
Foxboro Co.
General Electric Co.
Minneapolis-Honeywell Regulator Co., Brown Instruments Div.
Wallace & Tiernan Inc.

Refractory Building Materials
Carborundum Co.
Johns-Manville Sales Corp.
Stebbins Engr. & Mfg. Co.

Safety Equipment
Vapor Recovery Systems Co.

Sampling Equipment
Chicago Pump Co.
Infilco Inc.
Lakeside Engineering Corp.

Sand, Gravel, and Stone
Graver Water Conditioning Co.
Vulcan Materials Co.

Screening Equipment
Alpha Ltd. (Switzerland)
American Well Works
Chain Belt Co.
Chicago Pump Co.
Dorr-Oliver Inc.
Eimco Corp.
Infilco Inc.
Jeffrey Mfg. Co.
Link-Belt Co.
Walker Process Equipment Inc.
Zimmer & Francescon

Sedimentation Equipment (*also see* Clarifier Equipment)
Alpha Ltd. (Switzerland)
American Well Works
Ralph B. Carter Co.
Chain Belt Co.
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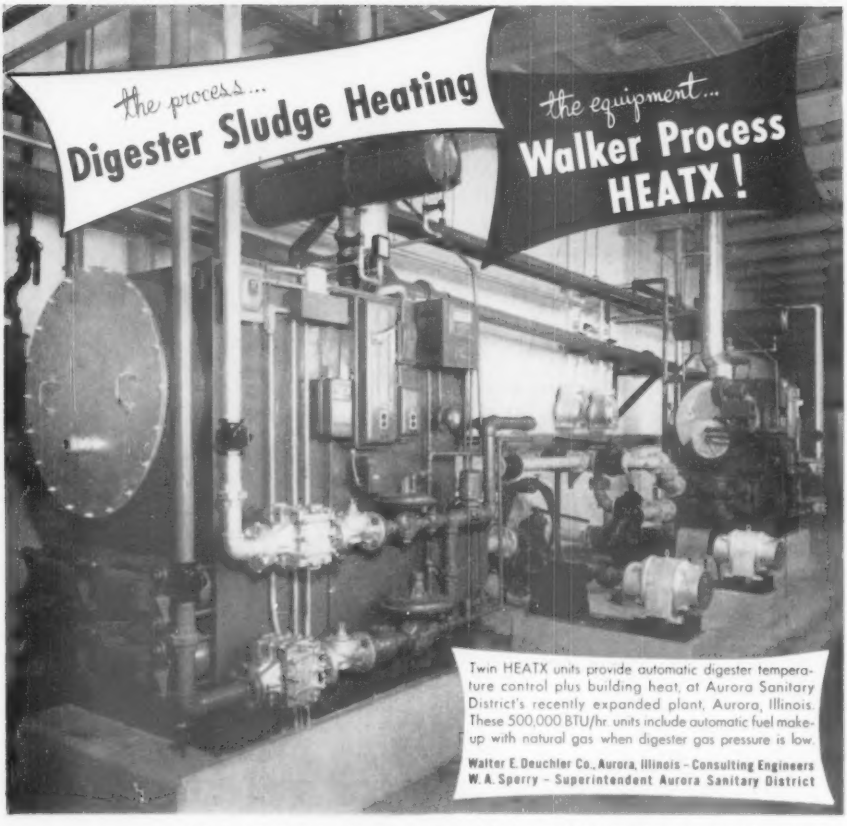
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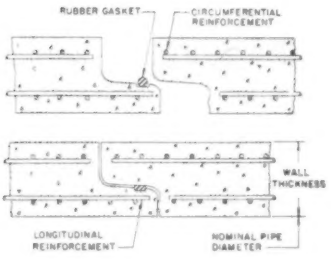

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